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TECHNOLOGY UTILIZATION

SELECTED ELECTRONIC CIRCUITRY

A REPORT

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NASA SP-5046

SELECTED ELECTRONIC CIRCUITRY

A REPORT

Prepared by
Northrop Space Laboratories
Hawthorne, California

Technology Utilization Division
OFFICE OF TECHNOLOGY UTILIZATION 1966
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

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FOREWORD

The Administrator of the National Aeronautics and Space Administration has established a Technology Utilization Program for "the rapid dissemination of information . . . on technical development . . . which appear to be useful for general industrial application." From a variety of sources, such as NASA Research Centers and NASA contractors, space-related technology is screened and that which has potential industrial use is made generally available. Thus, American industry will receive information from the nation's space program about the latest developments in operating techniques, management systems, materials, processes, products, and analytical and design procedures. This publication is part of a series designed to provide this technical information.

The advent of space exploration has occasioned large programs involving intensive research and resulting progress in electronic-circuit technology. These advances have come primarily from stringent requirements in areas of reliability, simplicity, fail-safe characteristics, and the capability of withstanding environmental extremes. It is the purpose of this publication to make an appropriate part of this research available to the public for use by those whose vocational or recreational activities are connected with electronic-circuit design, utilization or experimentation.

No inference should be drawn that all of the circuits are newly invented. Many of them are based on well-known solid-state concepts that have been simplified or refined to meet a space-program requirement. An attempt has been made to select elements of novel circuitry that will be of interest not only to the professional engineer, but to the electronics hobbyist as well.

GEORGE J. HOWICK, Director,
Technology Utilization Division
National Aeronautics and Space Administration

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GENERAL PUBLIC INFORMATION

This report is a summary of specific innovations in the electronics field derived from the space program. They have been compiled to acquaint industry with their technical highlights and encourage commercial application. Many of the innovations described in this volume have been printed as NASA Tech Briefs. Annual subscriptions for Tech Briefs in the Electrical (Electronic) category and orders for related special publications should be placed with:

Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

Additional technical information on individual circuits may be obtained by addressing the Technology Utilization Officer at the NASA center or office which is the listed source of the circuit. Inquiries should be directed to the appropriate address listed below, and reference should be made to the Tech Briefs (B64–) or source number (e.g., ARC–4) included in the circuit text:

Ames Research Center
Mountain View, California 94035

Flight Research Center
P.O. Box 273
Edwards, California 93523

Goddard Space Flight Center
Greenbelt, Maryland 20771

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

Langley Research Center
Langley Station
Hampton, Virginia 23365

Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Marshall Space Flight Center
Huntsville, Alabama 35812

Manned Spacecraft Center
Houston, Texas 77001

AEC-NASA Space Nuclear
Propulsion Office
U.S. Atomic Energy Commission
Washington, D.C. 20545

NASA Western Operations Office
150 Pico Boulevard
Santa Monica, California 90406

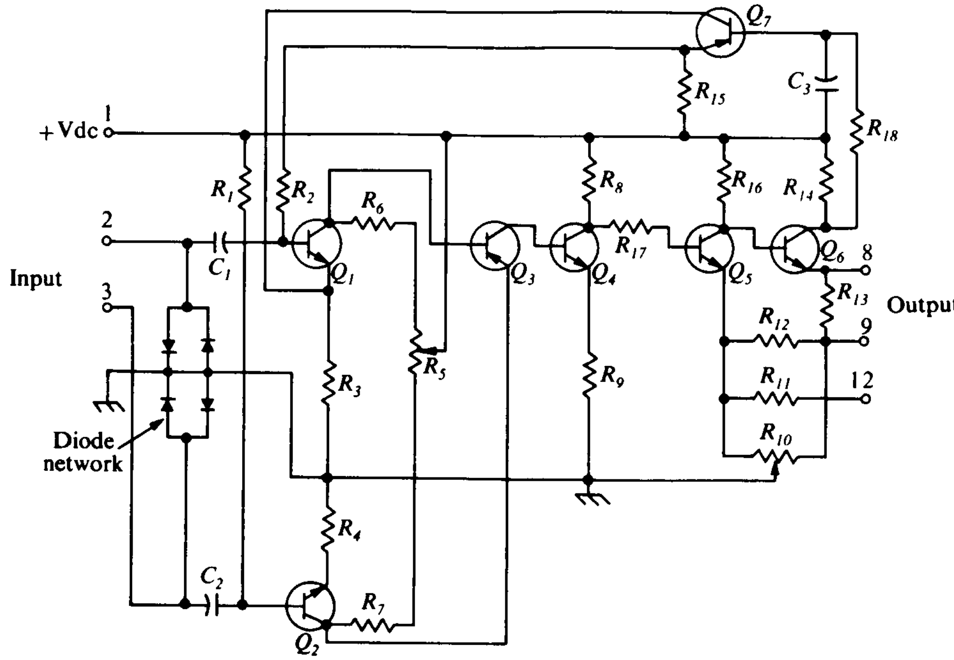
Other NASA Technology Utilization Publications in the broad area of circuit technology and electronics applications are available as follows:

NASA SP–5002	Reliable Electrical Connections
NASA SP–5011	Welding for Electronic Assemblies
NASA SP–5022	Micropower Logic Circuits
NASA SP–5031	Microelectronics in Space Research
NASA SP–5038	Magnetic Tape Recording

Section 1

AMPLIFIER CIRCUITS

Low-Level AC Amplifier



APPLICATION: This transistorized differential amplifier circuit was designed to amplify signals received from electrodes attached to the body of a person for the purpose of supplying an input to an electrocardiograph, and can be used in audio equipment as well. The circuit provides a very high-ratio common-mode rejection (10,000 to 1, referred to the input) and adjustable cancellation at the input for unbalanced noise signals. The circuit operates on a very low voltage supply to assure safety and includes a single active element across the input-output ends for automatic temperature compensation. An adjustable gain feature in the circuit does not require the use of matched input transistors. Operating on a 4-volt dc supply, the amplifier requires 8 milliwatts of power to produce a 1-volt peak-to-peak output with a 3.6 millivolt input signal.

CIRCUIT DESCRIPTION: A dc power supply (not shown) is connected to terminal 1. Input terminals 2 and 3 may be connected by balanced leads to the body of a person. The two terminals (2 and 3) are coupled through separate capacitors, C_1 and C_2, to the base of transistors Q_1 and Q_2. A diode network is connected between each of the input terminals 2 and 3 and ground in order to prevent saturation of Q_1 and Q_2 from overly large noise signals appearing in the input of the circuit. These diodes form low-resistance paths to a common ground lead for large input signals.

Identical input signals impressed upon the transistors Q_1 and Q_2 will produce corresponding voltage variations at the collectors of these transistors, so that no voltage change occurs between the base and emitter of transistor Q_3. This provides for conversion from a double-ended input to a single-ended output and at the same time provides for a common-mode rejection.

Adjustable noise cancellation is afforded by potentiometer R_5 which has resistors R_6 and R_7 coupled to the collectors of the input transistors Q_1 and Q_2, and a variable contact connected to the power supply of terminal 1. By changing the position of the variable contact, it is possible to increase the gain of one amplifier transistor while reducing the gain of the other and thus to balance the circuit when the noise levels at the two input terminals 2 and 3 are not equal.

Transistor Q_3 operates as a current source producing at its collector a current proportional to the signal from the bridge formed by Q_1 and Q_2. Following Q_3 is a direct-coupled amplifier including Q_4, Q_5, and Q_6.

An emitter-follower connection is used to supply the output signal from the amplifier and in this respect a resistor R_{13} is connected to the emitter of the transistor. Q_6, with output terminals 8 and 9 connected across this resistor. R_{12} is connected in parallel with the resistance of the potentiometer R_{10} and an additional output terminal 12 is coupled through R_{11} to the emitter Q_5.

The circuitry for automatic temperature compensation includes transistor Q_7 having its base coupled through resistor R_{18} to the collector of Q_6. Capacitor C_3 is connected from the base of Q_7 to the power supply for bypassing ac signals, so that only dc signals are fed back to the input of the amplifier. Negative feedback is employed, so that the dc signals returned to Q_1 are of opposite polarity to the dc output variations of the amplifier, and serve to cancel these variations. In this way compensation is provided to prevent direct-current drift of the circuit with variations in temperature of the circuit components.

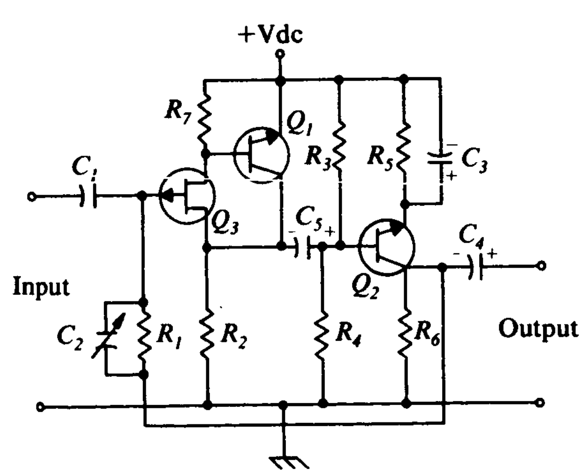
DESIGN CONSIDERATION: This circuit can typically be constructed for an operating frequency range from 0.3 to 70,000 cps. The low-frequency response is determined by the characteristics of the temperature-compensating network.

Typical circuit elements and component values include:

Q_1, Q_2, Q_4, Q_5, Q_6	2N78
Q_3, Q_7	2N416
Supply	+4 Vdc
R_1	10K
R_2	470K
R_3, R_4, R_5, R_6	4.7K
R_7, R_{15}	500 Ω
R_8, R_{11}	10K
R_9	150 Ω
R_{10}	100K
R_{12}, R_{13}, R_{14}	22K
R_{16}	2.2K
R_{17}	1.2K
R_{18}	68K
C_1, C_2	10 μF
C_3	330 μF

SOURCE: Joseph R. Smith, Jr.
Ames Research Center
(ARC–2)
B63–10003

Electrometer Amplifier Using Field-Effect Transistor



APPLICATION: This electrometer amplifier circuit uses a field-effect transistor (FET) to measure currents as low as 10^{-13} ampere at room temperature with a 1-cycle bandwidth and approaching the theoretical noise limit. The circuit can be applied to electrometer amplifiers used in measuring very small currents.

CIRCUIT DESCRIPTION: This is an ac amplifier circuit to be used with an external filter which limits bandwidth to achieve optimum noise performance. Transistors Q_1 and Q_2 are used in the input stage as a close-coupled feedback pair to achieve in-phase operation and cancellation of source-to-gate capacitance in the FET Q_3.

Transistor Q_2, by feedback, improves the gain of the input source-follower circuit from a value of approximately + 0.6 to very nearly + 1.0. Direct current bias in the FET is accomplished through the feedback resistor R_1, thus eliminating the noise-producing biasing resistors ordinarily used. The amplifier draws only 4.5 milliwatts and is useful in the frequency range from 100 cps to several kilocycles.

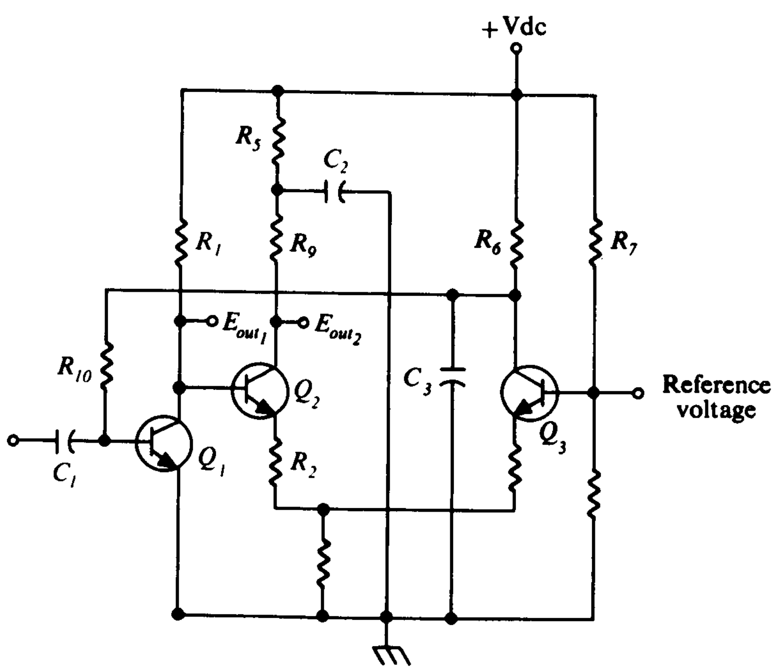
DESIGN CONSIDERATION: Capability of this circuit depends on the FET characteristics of low noise and high leakage resistance. The circuit sensitivity can be increased by using FET types with the highest available leakage resistance.

Typical circuit elements and component values include:

Q_1	2N697
Q_2	2N2484
Q_3	2N2606
Supply	— 12 Vdc
R_1	100 MΩ
R_2	47K
R_3	100K
R_4	470K
R_5	6.8K
R_6	22K
R_7	18K
C_1	1000 pF
C_2	0–1 pF
C_3	10 μF
C_4	1 μF
C_5	1 μF

SOURCE: Robert Munoz
Ames Research Center
(ARC–36)
B64–10143

High-Gain Amplifier



APPLICATION: This circuit is an example of a transistorized amplifier combining high-gain with stability and very low power consumption. The circuit gain is controlled by an external reference voltage. Voltage gain at E_{out_1} is stated by the relation 39FV, where

$$F = \frac{V - E_{out_1}\,(dc)}{V}.$$

Higher gain may be obtained at E_{out_2} but will not be as stable as E_{out_1}. The circuit can be applied to servo equipment and portable audio devices.

CIRCUIT DESCRIPTION: Gain of the amplifier Q_1 is stabilized by using a difference amplifier circuit Q_2 and Q_3 to sense and correct changes in its operating point. This dc operating point is controlled by the difference amplifier Q_2 and Q_3 through the feedback loop from the collector of Q_3 to the base of Q_1. Varying the reference voltage to the base of Q_3, therefore, varies the ac gain of the amplifier Q_1.

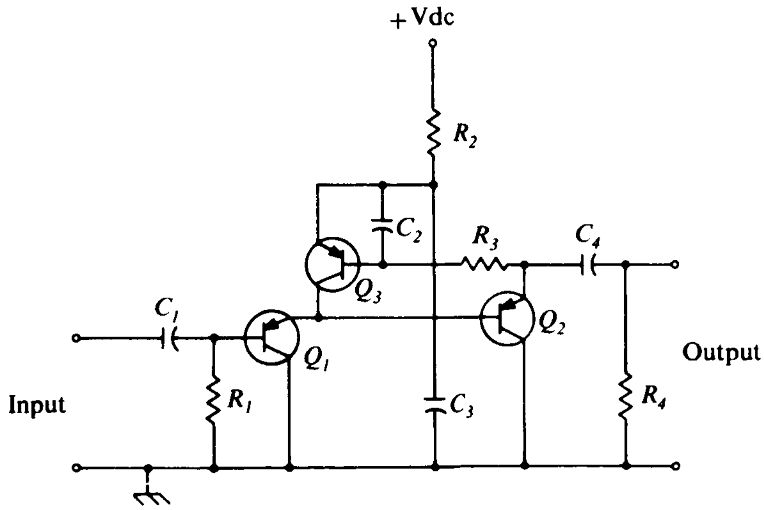
DESIGN CONSIDERATION: Stability of this circuit depends on the use of quality components including transistors with beta greater than 100. If a varying reference signal is applied to the base of Q_3, the amplifier can be used as a variable gain modulator.

Typical circuit elements and component values include:

Supply	20V
Q_1, Q_2, Q_3	2N930
R_1, R_7, R_8	10K
R_2, R_3	5.1K
R_4, R_6	510K
R_5	390K
R_9	100K
R_{10}	3.3 MΩ
C_1	10μF
C_2	0.1μF
C_3	0.001μF

SOURCE: Leonard L. Kleinberg
Goddard Space Flight Center
(GSFC-272)
B65-10138

Transistorized Emitter-Follower Amplifier



APPLICATION: This is an example of a simple, reliable transistor circuit design for an amplifier for driving low-impedance loads from high output-impedance pulse devices.

CIRCUIT DESCRIPTION: The circuit features high input impedance through R_1 while maintaining high-gain and linearity (without resorting to boot strapping) especially for fast-pulse applications. This is accomplished by inclusion of current biasing transistor Q_3 which allows the input transistor Q_1 to draw a reasonable amount of quiescent bias current which does not have to pass into the base of

Q_2 or be shunted to ground or to the emitter of Q_2 by a resistor.

Current biasing transistor Q_3 holds the output emitter ($Q_{3\epsilon}$) close to the supply voltage and preserves a large available dynamic signal swing, independent of temperature.

Use of an amplifier with low quiescent current biases of transistors allows R_1 to be extremely high ($R_1 \cong 250$ megohms) and the input impedance approaches that of ideal emitter follower, where $R_1 \cong \beta 1\ \beta 2\ R_L$, for values of R_1 equaling 10 megohms or less.

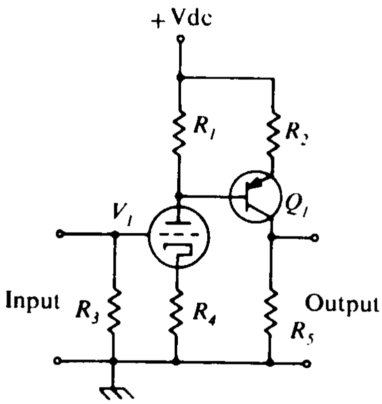
The combination of R_2, C_3 decouples fast line transients from the signal, and fast signal transients from the line. R_3, C_2 also prevents signal transients from circulating in the negative feedback bias loop. C_2 also raises the collector ac output impedance of Q_3 to common base values.

Typical circuit elements and component values include:

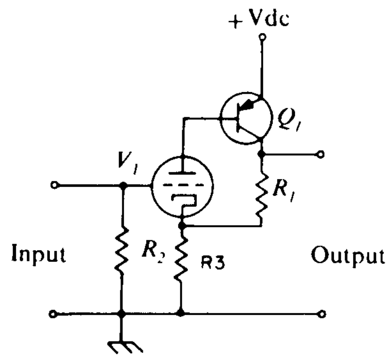
Q_1, Q_2, Q_3	HA9010 (Hughes)
Supply	+ 9 to 15 Vdc
R_1	1.0 MΩ
R_2	330 Ω
R_3	15K
R_4	3.3K
C_1	1000 pF
C_2	1.0 μF
C_3	10 μF
C_4	0.47 μF

SOURCE: Lanny L. Lewyn
Jet Propulsion Laboratory
(JPL–275)

Simplified Electrometer



Previous circuit



Improved circuit

APPLICATION: This is a simple electrometer circuit which has stability of gain and operating point, high input impedance, linear response, and low power requirements. This circuit can be useful where amplifier linearity and stability are required, such as in electrometer application.

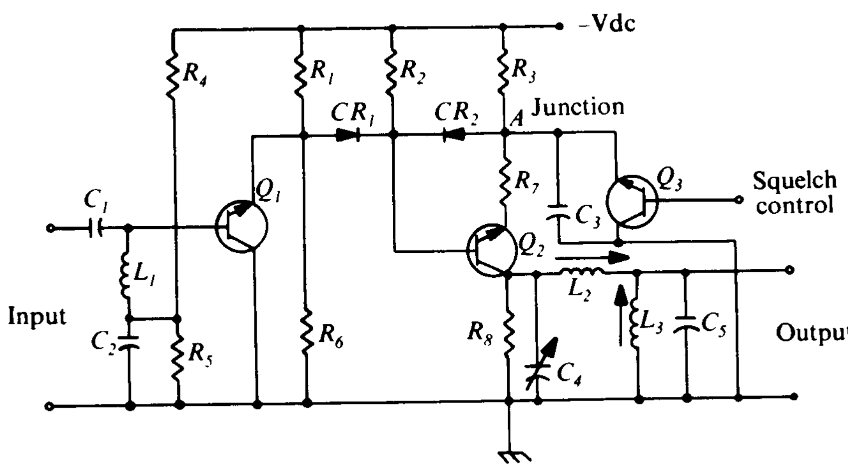
CIRCUIT DESCRIPTION: The operating characteristics of a typical electrometer amplifier are improved by modifying the circuit as shown. The previous circuit had a load resistor, R_1, in the plate circuit of the electrometer tube V_1, and a bias resistor, R_2, in the emitter of the input transistor Q_1. The effect of both of these resistors is to reduce the open loop gain of the circuit and to increase the power requirements.

In the improved circuit the base-emitter junction of transistor Q_1 is used as the plate load of the amplifier input electrometer tube V_1, and the collector of the transistor is connected to the following amplifier stage and to a feedback circuit including resistor R_1. This feedback greatly improves the linearity of the electrometer over its operating range and improves the operating point stability and input impedance. No source current is dissipated in a plate load resistor and no degeneration occurs from an emitter bias circuit paralleling the plate load.

Component values and parts list were not available at the time of publication.

SOURCE: Roy E. Brantner
Jet Propulsion Laboratory
(JPL-413)
B65-10125

Variable Gain, Wide Band *IF* Amplifier



APPLICATION: This circuit configuration is a variable gain, wide band, solid-state *IF* amplifier, suitable for cascading into multistage circuits, and possessing relatively constant input and output impedances. This circuit is well adapted to *IF* amplifier applications where constancy of pass-band and phase characteristics are important and where up to 25 db output signal handling capability is required. Approximately 80 db of control is available for squelch purposes.

CIRCUIT DESCRIPTION: The circuit differs from conventional variable gain *IF* amplifiers in that the elements which control the gain consist of diodes CR_1 and CR_2. The values of resistors R_1, R_2, and R_3 are selected so that at amplifier maximum gain conditions: CR_1 is biased into a conducting state; CR_2 is biased into a non-conducting state; Q_3 is biased to cut-off; and transistors Q_1 and Q_2 are biased to the center of their rated current ranges. Under these conditions, Q_1 and Q_2 operate as two cascaded amplifier stages which are directly coupled by CR_1.

To vary the amplifier gain, AGC current is applied to the base of Q_3, causing Q_3 to conduct, which in turn causes junction A to become more positive. As A becomes more positive, CR_2 becomes conductive and in turn biases CR_1 towards a non-conducting state. In this manner, CR_1 and CR_2 act as an electronically operated voltage divider placed between the output of Q_1 and the input of Q_2. As the ratio of conductance between CR_1 and CR_2 is varied, the coupling between Q_1 and Q_2 is correspondingly varied, thus controlling the amplifier gain.

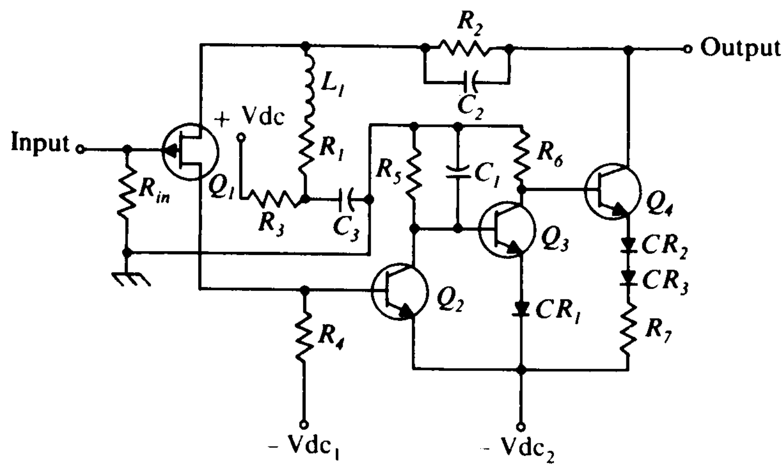
Throughout the normal operating AGC range, the bias point of Q_2 remains reasonably fixed because its base and emitter voltages are simultaneously varied by the combined actions of CR_1, CR_2, and Q_3. Accordingly, the output impedance of Q_2 remains relatively constant. As the operating parameters of Q_1 are virtually unaffected by the AGC action, the input impedance of Q_1 also remains relatively constant.

DESIGN CONSIDERATIONS: Care must be exercised to adjust biases to achieve the desired operating conditions.

Component values and parts list were not available at the time of publication.

SOURCE: R. C. Mullick
Jet Propulsion Laboratory
(JPL-470)

High-Impedance Input AC Amplifier



APPLICATION: This is a four-stage transistorized amplifier circuit using a field effect transistor in the first stage to provide a stable high input impedance and low intrinsic noise levels. The circuit is suited to carrier or narrow-band sine wave applications since the bandpass and gain may be easily controlled. The large intrinsic bandwidth and good transient response make the circuit suitable for use on pulse systems.

CIRCUIT DESCRIPTION: An input signal is applied to the gate of the field-effect transistor Q_1, which is a majority-carrier device and free of the noise associated with minority-carrier current flow. The gate presents an impedance on the order of 10^9 ohms; therefore the actual impedance presented to the signal is determined by the magnitude of R_{in}. The first stage provides a voltage gain of 20. Transistors Q_2, Q_3, and Q_4 are direct-coupled to provide three additional stages of amplification. The total open-loop voltage gain of all four transistors is 3×10^6.

The high-frequency response is determined by the time constants of the four transistors and the feedback network (R_1, L_1, R_2, C_2). A closed-loop midband voltage gain of 1000 is attained with a feedback factor of 3000 (ratio of current in R_2–C_2 to current injected at Q_1 source). A low closed-loop gain for dc prevents input drifts from producing excessive shifts in output operating points. Temperature variations from $-55°$ to $+125°$ C produce a closed-loop midband gain variation of approximately $\pm$ 0.1 percent.

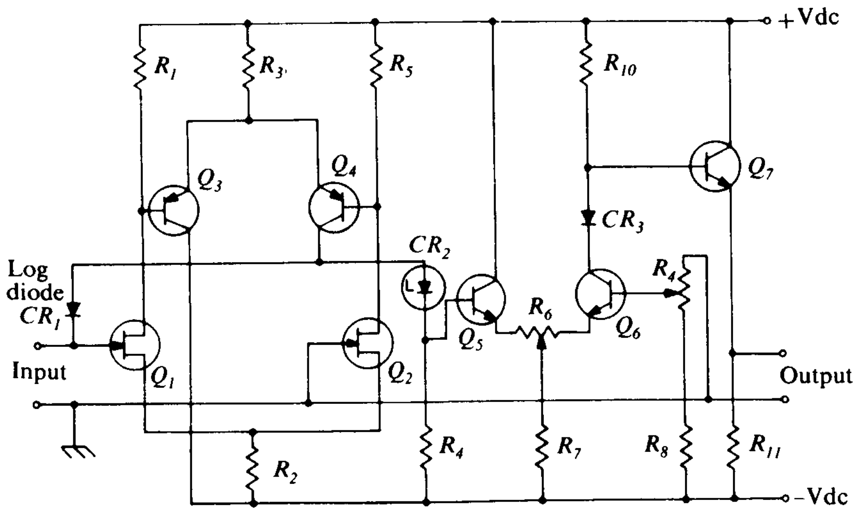
DESIGN CONSIDERATION: The low-frequency cutoff, determined by R_1, C_3, occurs at 159 cps. The circuit has a rise time of 3 microseconds, an 8 percent overshoot, and consumes a small amount of power compared to conventional bootstrap amplifiers.

Circuit elements and component values for a typical circuit are as follows:

Q_1	2N2497
Q_2, Q_3, Q_4	2N930
CR_1, CR_2, CR_3	1N457
L_1	10 μH
C_1	0.03 μF
C_2	100 pF
C_3	100 μF
R_{in}	10 MΩ
R_1	10 Ω
R_2	10K
R_3	31.6K
R_4	28K
R_5, R_6	82K
R_7	430 Ω
$-\mathrm{Vdc}_1$	$-$20.5V
$-\mathrm{Vdc}_2$	$-$10V
$+\mathrm{Vdc}$	$+$19V

SOURCE: J. H. Marshall
Jet Propulsion Laboratory
(JPL-500)
B65-10232

Logarithmic Amplifier Uses Field Effect Transistors



APPLICATION: This circuit can find use in temperature compensation and general analog amplifier applications.

CIRCUIT DESCRIPTION: This circuit is a temperature-stabilized operational amplifier composed of three differential amplifier stages, an emitter-follower output stage, and a planar-junction logarithmic diode.

The required logarithmic response to an unusually large range of input current variation is achieved by using two n-channel field-effect transistors, Q_1 and Q_2, for the first differential amplifier stage. These transistors are also sensitive to very small current due to their high input impedance.

The two field effect transistors, Q_1 and Q_2, drive the second differential amplifier stage, Q_3 and Q_4. The output of Q_3 is applied to the final differential amplifier stage, Q_5 and Q_6, and to the planar-junction logarithmic diode, CR_1. By inserting CR_1 in the feedback path to the first differential amplifier stage, the logarithmic output of the circuit is achieved.

The output of Q_6 is applied to Q_7, which is operated as an emitter-follower. This configuration provides a high output impedance for the amplifier. The differential character of the amplifier is basically for temperature compensation.

This is an example of a simple, reliable circuit which has wide signal handling range without the requirement for a switching network. The use of field effect transistors provides a high signal-noise ratio and favorable impedance matching characteristics. The circuit has a logarithmic response to signals ranging from 10^{-12} to 10^{-4} ampere.

DESIGN CONSIDERATIONS: Circuit components should be matched for optimum overall characteristics. The final output voltage, E_o, taken between the emitter of Q_7 and ground, will be

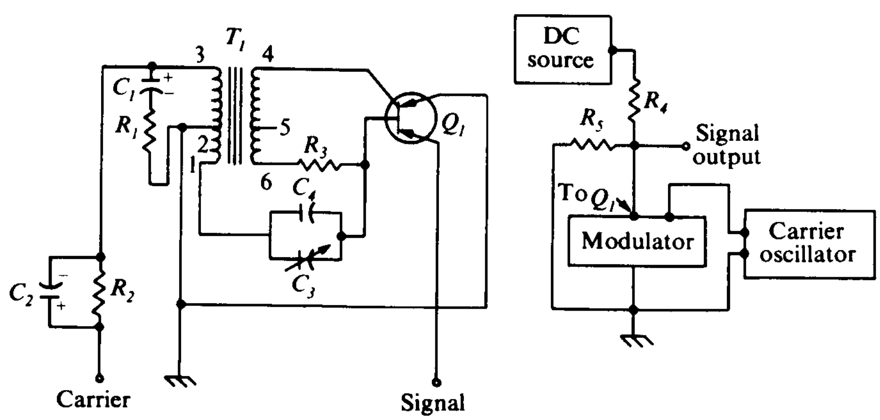
$$E_o = K_1 \log (5 \times 10^{11} I_{in} + 1) + K_2$$

Typical circuit elements and component values include:

Q_1, Q_2	FSP401
Q_3, Q_4	FSP251-1
Q_5, Q_6	2N2060
Q_7	2N1711
CR_1	Log Diode
CR_2	2N915
CR_3	1N457
Supplies	+ 10 Vdc, − 10Vdc
R_1	100K
R_2	75K
R_3	16K
R_4	47K
R_5	100K
R_6	5K
R_7	43K
R_8	47K
R_9	5K
R_{10}	47K
R_{11}	27K

SOURCE: J. L. Stewart
Jet Propulsion Laboratory
(JPL-509)
B65-10145

Solid State Modulator for DC Amplifier



APPLICATION: This circuit is designed to modulate direct current signals over a voltage range of $\pm 5 \times 10^{-6}$ to ± 5 Vdc, a million to one ratio. Important features of the circuit are low noise level and low offset voltage. The circuit can be utilized in amplifying dc signals from low output transducers of medical instrumentation and the output signals from strain gages and thermocouples.

CIRCUIT DESCRIPTION: The modulator circuit is designed around a commercially available solid state chopper, transistor Q_1. The carrier signal is the switching signal for Q_1. Q_1 acts as a switch operating at the frequency of the carrier to pulsate the dc voltage applied to the signal lead.

The characteristics of the modulator are as follows:

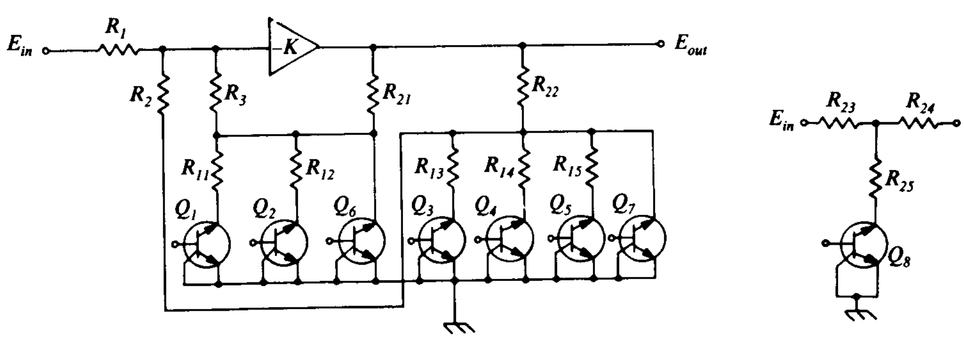
Carrier range	400 to 5000 cps
dc signal source impedance (single-ended)	50,000 Ω
Output load impedance (single-ended)	20,000 Ω
Maximum dc offset	
− 15° to 75° C offset of	0.5 mV
− 15° to 100° C offset of	1.5 mV
Phase shift over carrier frequency range	Less than 5°
Signal voltage over signal range	± 2%

DESIGN CONSIDERATIONS: Typical elements and component values include:

Q_1	3N66	
T_1	Triad SP–66 TF5RX13ZZ	
C_1	0.15 μF	
C_2	0.27 μF	
C_3	2–8 pF	
C_4	15 pF	
R_1	220 Ω	1/10 watt
R_2	680 Ω	1/10 watt
R_3	6.8K	1/10 watt
R_4	50K	
R_5	20K	

SOURCE: Decker Corporation
under contract to
Marshall Space Flight Center
(M–FS–144)

Electronic Gain Switching for a Differential Amplifier



APPLICATION: This circuit built of solid state components provides a means of electronic gain switching by remote control of a differential amplifier. This control circuit can be utilized in spaceborne instrumentation application and for gain switching in industrial systems.

CIRCUIT DESCRIPTION: The circuit uses a new type transistor (NS3000), developed by the National Semiconductor Company, as a switch to change the gain of the amplifier by changing the feedback resistance of the circuit. When a positive voltage is applied to the base of each transistor it is turned ON, thereby applying the resistance of that leg of the circuit to the amplifier feedback resistance. With the use of combinations of positively energized transistors the overall gain of the circuit is variable in discrete steps. Varying the gain in steps achieves a high dynamic range.

The circuit as illustrated is made up of two beta feedback networks connected in parallel. The gain of the circuit can be controlled by either one of these networks or by the combination of both. To determine a particular gain for one stage of this circuit, the transfer function can be determined as follows: $\frac{R_2}{R_1} \times \frac{1}{\beta}$ where $\beta = \frac{R_{13}}{R_{13} + R_{22}}$. Transistors Q_6 and Q_3 must be turned ON and Q_1, Q_2, Q_4, Q_5, and

Q_7 must be OFF. Q_6 and Q_7 shunt the feedback resistors of each network to ground when they are not in use as gain determining resistors.

DESIGN CONSIDERATIONS: A further extension of the dynamic range can be achieved by using the alternate input circuit shown (right) in place of R_1. Resistor R_{25} and transistor Q_8 form an ammeter shunt. Resistor R_{24} is chosen so that $R_{23} + R_{24}$ is about equal to R_1. A typical shunt ratio R_{25}/R_{24} is 1/20. This extends the dynamic range without sacrificing the signal-to-noise ratio. The amplifier can be made as dynamic as desired by having more than one ammeter shunt and having many feedback resistors or paralleling as many beta networks as needed. The NS3000 transistor has an ON impedance of less than 50 ohms and OFF impedance greater than 10^9 ohms.

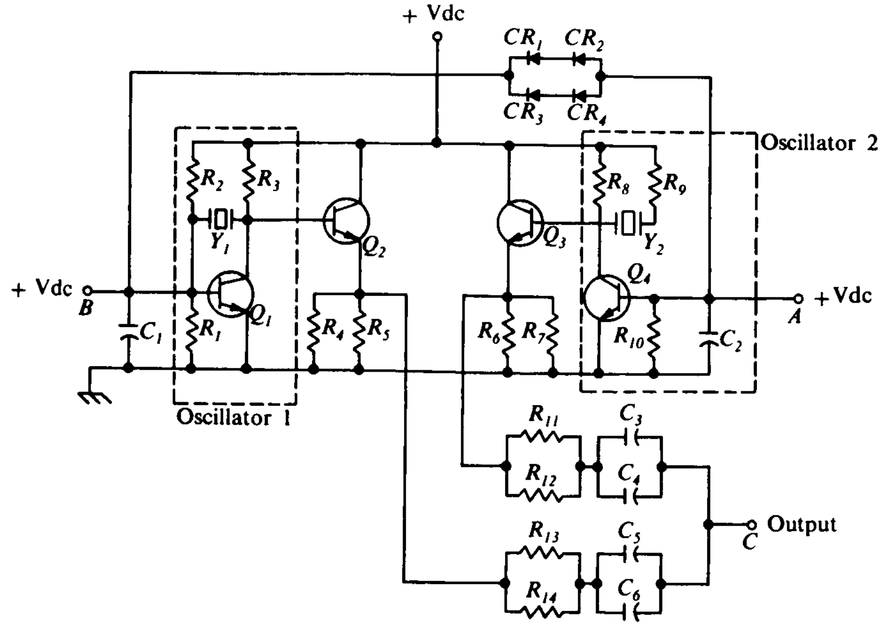
Component values and parts list were not available at the time of publication.

SOURCE: George I. Reeves
Beckman Instruments, Inc.
under contract to
Manned Spacecraft Center
(MSC–79)

Section 2

OSCILLATOR CIRCUITS

Dual Redundant Oscillator



Application: This dual redundant oscillator can be utilized to maintain critical oscillator operation by automatic switching between two units without external circuitry. The circuit features reliability through redundancy and can be used as a crystal oscillator frequency source for remote transmitter and receiver applications.

Circuit Description: Transistor Q_1 and Q_4, in conjunction with the respective crystals Y_1 and Y_2, and circuit constant elements, form separate oscillator circuits. Either or both circuits will supply the correct frequency and output amplitude to the next stage or module. Transistors Q_2 and Q_3 are isolation amplifiers for oscillators 1 and 2, respectively, and are parallel connected through isolation networks to the output, point C.

Oscillator 1 is prime and, when in operation, supplies an integrated negative signal through the diode clamp, CR_1, CR_2, CR_3, and CR_4, to the base circuit of oscillator 2. This negative signal provides a bias for an OFF or low amplitude condition for oscillator 2. Thus, under normal conditions, oscillator 1 supplies the signal at crystal Y_1 frequency through amplifier Q_2, at correct amplitude, to point C. If oscillator 1 output amplitude falls below the selected value, bias is relieved from oscillator 2, which then assumes the burden for signal delivery to the output. Synchronization is not required since the output from only one of the two oscillators is present, at any time, at point C.

Design Consideration: The bias voltage must be selected so that the diode clamps, CR_1 through CR_4, are just above condition threshold when no signal is present. The circuit constants must be selected for Q_1 and Q_4 to assure amplitude equalities at point C. This is necessary due to the differences in circuit elements placement between the two circuits. Crystals Y_1 and Y_2 must be selected for frequency differential to the order of accuracy required for the usage. The output networks should reflect at least a 3 to 1 impedance ratio with respect to the characteristic output impedance of the emitter follower isolation amplifiers, Q_2 and Q_3.

Typical circuit elements and component values include:

Q_1, Q_2, Q_3, Q_4	4210AA
CR_1, CR_2, CR_3, CR_4	1N658
R_1, R_{10}	120K
R_2	2 MΩ
R_3, R_8	10K

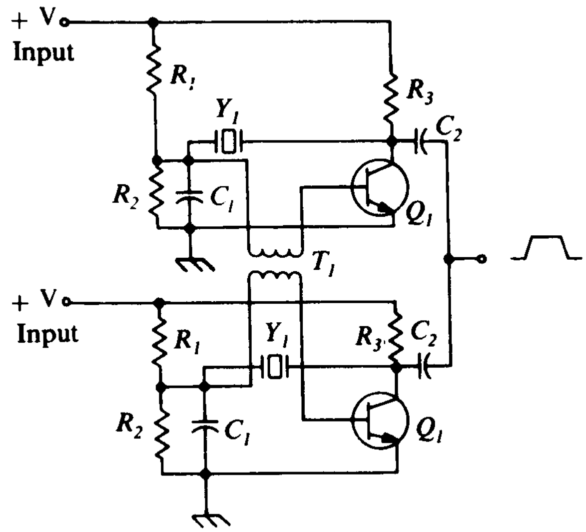
R_4, R_5, R_6, R_7	2K
R_9	1.8 MΩ
$R_{11}, R_{12}, R_{13}, R_{14}$	3.9K
C_1	220 μμF
C_2	120 μμF
C_3, C_4, C_5, C_6	.01 μF

SOURCE: W. M. Nolis
International Business Machines
under contract to
Goddard Space Flight Center
(GSFC-36)
B63-10027

Synchronized Redundant Oscillator

APPLICATION: This synchronized redundant oscillator circuit can be used in redundant operations when either oscillator may fail without interaction with the other stage. The circuit provides a means of connecting two or more oscillators so they are synchronized and the circuit generates a square-wave output. The circuit can be utilized in general electronics applications where redundancy is employed for increased reliability and simplicity, and in equipment not easily reached for maintenance.

CIRCUIT DESCRIPTION: This circuit uses a pair of crystal oscillators interconnected by an air-core transformer T_1. The collectors of transistor Q_1, in each circuit, are connected to provide a common output. In each oscillator, one winding of transformer T_1 is used as an inductor in the base circuit of transistor Q_1. A piezoelectric crystal Y_1 is connected in parallel with the inductance of the winding of T_1 and the base-collector circuit of Q_1. The collector of Q_1 is connected through resistor R_3 to the voltage source and power is supplied to the base of Q_1 through a voltage divider comprised of resistors R_1 and R_2. Transformer T_1 provides a large voltage swing at the base of Q_1 driving the transistor from saturation to cutoff and thus produces square wave output. Transformer T_1 defines a current limiting resistance at the oscillator frequency so that the maximum dissipation of the crystal is not exceeded.



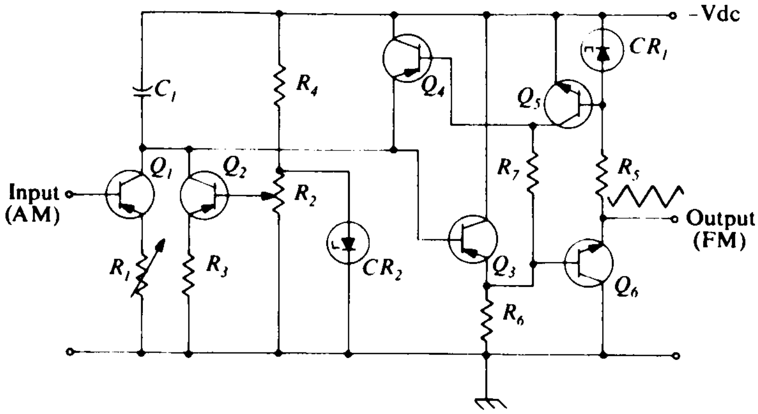
When both oscillators are operating, they are synchronized by the aircore transformer. Either oscillator may fail without loss of the square wave output since failure in one stage will not cause saturation of the winding of the transformer connected with the other stage.

DESIGN CONSIDERATION: T_1 is a non-saturable transformer.

Component values and parts list were not available at the time of publication.

SOURCE: W. W. Craig
International Business Machines
under subcontract to
Goddard Space Flight Center
(GSFC-65)

AM To FM Converter



APPLICATION: This circuit is designed to convert amplitude modulated (AM) information to frequency modulated (FM) information. This conversion is accomplished by a type of relaxation oscillator, the output signal being initiated by the charge and discharge cycles of a capacitor. This circuit can be utilized in radar, telemetry, and test equipment.

CIRCUIT DESCRIPTION: Capacitor C_1 is charged by the current flow through transistors Q_1 and Q_2 and discharged by the action of tunnel diode CR_1, resistor R_5, and the base to emitter junctions of transistors Q_3 and Q_6.

Transistor Q_2 produces a steady current flow which is controlled by the bias setting of R_2. The effect of this current in the charging of C_1 is equivalent to the carrier frequency of a standard FM signal. Adjusting R_2 raises or lowers the steady-state frequency of the carrier.

Transistor Q_1 produces a current which is a function of the AM signal applied to the input terminal. The effect of this current in the charging of C_1 is to vary the frequency above and below the carrier point, equivalent to the modulation of the FM signal. The frequency of modulation is proportional to the amplitude of the input signal. Adjusting resistor R_1 will control the percentage of modulation or the number of cycles that the signal will depart from the carrier position.

As the charging current flows into C_1, the resulting voltage across C_1 is distributed through CR_1, R_5, and the base-to-emitter junctions of Q_3 and Q_6. CR_1 is biased at the peak-voltage point while Q_4 and Q_5 are both biased to cutoff.

As the voltage across CR_1 reaches the peak-voltage point, CR_1 switches to the high voltage —low current mode, Q_5 conducts, Q_4 conducts, and C_1 discharges through the low impedance of Q_4. The voltage developed across the base to emitter junctions of Q_3 and Q_6 is amplified to provide a triangular waveform FM output signal.

DESIGN CONSIDERATION: It is important to adjust biases with no input signal to ensure that Q_4 and Q_5 are at cutoff and CR_1 is at the peak voltage point. Q_3 and Q_6 should be biased at the midpoint of their operating current curve.

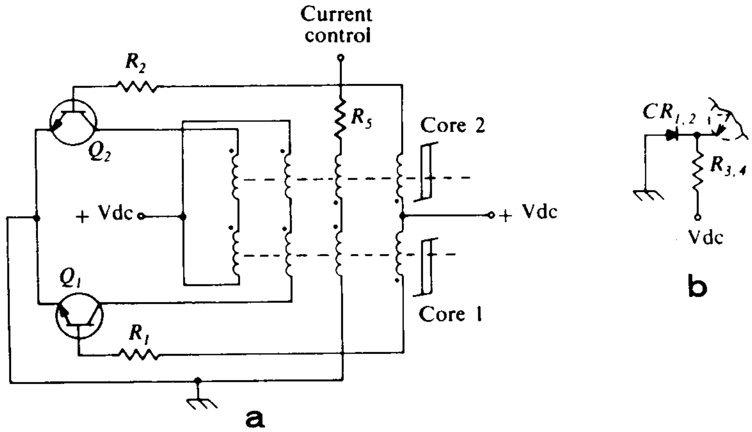
Typical circuit elements and component values include:

Q_1, Q_2, Q_3	2N1131
Q_4	2N501
Q_5, Q_6	2N916
CR_1	1N653
CR_2	1N752A
R_1, R_3	10K

R_2	5K
R_4	3.6K
R_5	1K
R_6	68K
R_7	5.1K
C_1	1000 $\mu\mu$F

SOURCE: Ta Tzu Wu
Radio Corporation of America
under contract to
Goddard Space Flight Center
(GSFC-227)
B65-10001

Current Controlled Oscillator



APPLICATION: This circuit can be used where a stable frequency in the 3 Kc to 50 Kc range is required, such as distance measuring devices and control of motors. The circuit features improved frequency stability and symmetry of output with varying input voltage and alleviates the requirement for transistors having critical characteristics.

CIRCUIT DESCRIPTION: This circuit varies from a normal voltage controlled oscillator by connecting two core windings in series with each of the transistor collectors, holding the voltage, + V constant, and with control maintained by a dc current applied to an extra set of windings. Current flowing into any dot of the circuit constitutes a positive magnetic drive so that when transistor Q_1 is conducting, both cores are being driven to higher flux. The control current drives one core positive and the other negative. With each control winding having the same number of turns as the collector windings, drives caused by the collector and control currents are on the same scale.

Increasing control current causes the trajectories to traverse less flux, thereby increasing frequency since the driving voltage is constant. Output voltage can be taken from extra windings or from collector to collector, etc., and will be constant since voltage is constant.

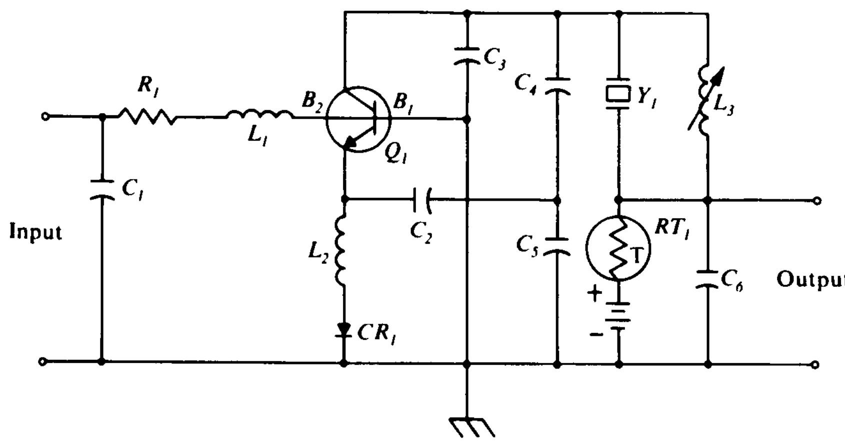
DESIGN CONSIDERATIONS: To induce rapid triggering, components shown in sketch b may be added to each emitter. With these components added, when the current rises to the value set by E and R_1, the emitter voltage rises with increased current. This lowers the core and drive voltages accordingly. More important is the fact that rising emitter current tends to cut the transistor off. The current E/R may be set by observing collector current in a particular circuit with the emitter grounded. The circuit must be loaded if a load is intended, since the observed collector currents depend on load.

Typical circuit elements and compound values for the composite circuit include:

Supplies	+ 10 Vdc, − 10 Vdc
Bias Supply	+ 10 Vdc divided by 4.7K and 220 ohms
Current Control	0 to 100 Vdc through R5, 10K
Q_1, Q_2	904
CR_1, CR_2	HD2018
R_1, R_2	4.7K
R_3, R_4	12K
Collector Windings	250 turns
Base Windings	100 turns
Control Windings	250 turns

SOURCE: Leon F. Edleson
Jet Propulsion Laboratory
(JPL–0028)

Current-Controlled FM Oscillator



APPLICATION: This circuit features a tetrode-driven oscillator in which the frequency is controlled by variation of the second base (B_2) current of the transistor tetrode operated in the reverse mode. The circuit can find use in small FM transmitters and VCO applications.

CIRCUIT DESCRIPTION: The crystal Y_1 serves as a resonating element in a standard feedback oscillator. In normal operation, current flows out of B_2 and input capacitance is shunted by the low resistance of the forward-biased emitter-base diode CR_1. This effectively reduces the change in frequency that could otherwise be obtained by varying the input capacitance.

The improved circuit operates on the characteristic change in output capacitance achieved by causing B_2 current to flow in the direction opposite to (toward or into B_2) flow in the normal mode. Collector bias is such that the thermistor RT_1 regulates the collector first base (B_1) voltage and thus the output capacitance to compensate for any decrease in frequency with temperature. In this mode, increases in B_2 current are used to change output capacitance and thus change frequency of oscillation.

DESIGN CONSIDERATION: Circuit performance may be difficult to predict exactly due to varying characteristics which tetrode transistors may exhibit. However, component selection and circuit adjustments can be employed to provide the desired operating control and stability.

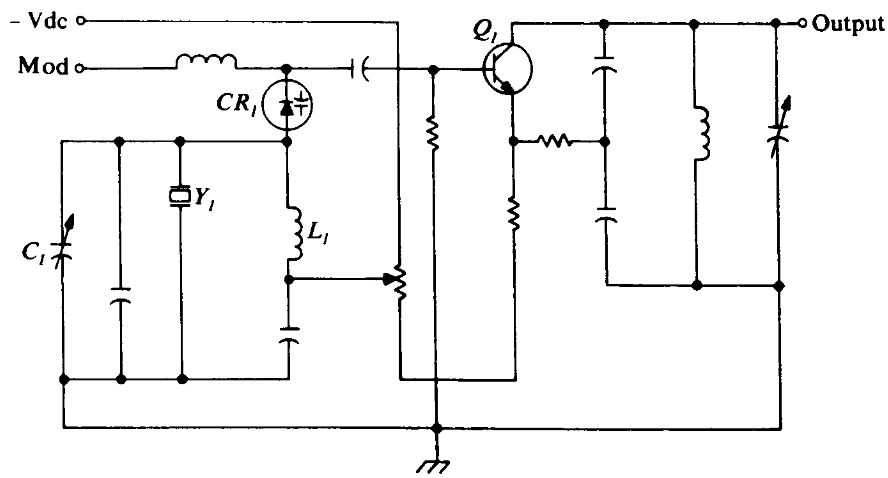
Typical circuit elements and component values include:

Supply	4 Vdc
Q_1	T1926
CR_1	To allow 0.5 mA
RT_1	10K @ 25° C (Fenwal 4151)

Y_1	For 455 kc	L_1	2.5 mH
R_1	15K	L_2	2.5 mH
C_1	0.01 μF	L_3	480–800 μH
C_2	0.5 μF		
C_3	82 pF		
C_4	200 pF		
C_5	220 pF		
C_6	0.5 μF		

SOURCE: Donald W. Boensel
Jet Propulsion Laboratory
(JPL–82)
B65–10055

Crystal Stabilized Voltage Controlled Oscillator with High Deviation



APPLICATION: This oscillator circuit could find general use in any FM transmitter application.

CIRCUIT DESCRIPTION: Transistor Q_1 is the oscillator transistor in this voltage controlled oscillator circuit. Utilizing the technique of stray capacity neutralization in the crystal circuit makes the varicap capacity changes have a larger effect on the frequency determining parameters of the crystal. This technique can be further developed to obtain frequency deviations as high as 0.1 percent of the carrier frequency with harmonic distortion lower than 5 percent and carrier frequency stability better than 0.002 percent.

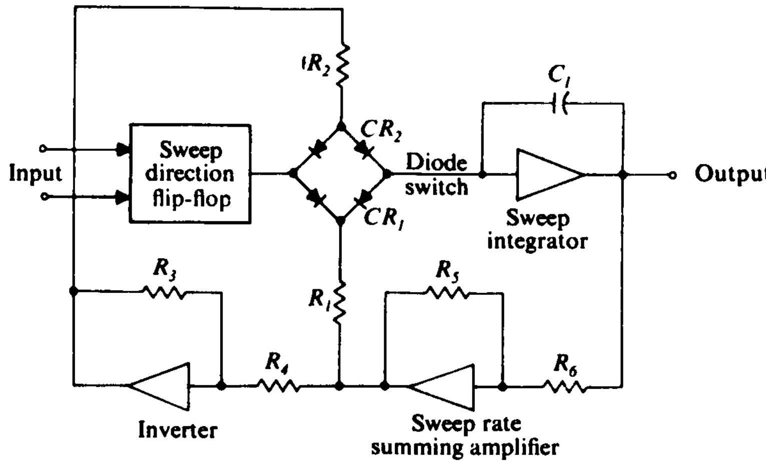
In the tuned-base, tuned collector arrangement, the base circuit must be series tuned to a frequency in the vicinity of the collector circuit parallel resonance frequency. Feedback is supplied from a collector tap to the emitter. A series resonant fundamental crystal Y_1 and varicap CR_1 are used with an associated neutralizing network L_1 and C_1 to tune the base circuit. The amount of frequency deviation is proportional to the magnitude of modulating voltage and the neutralization constant. The neutralization constant is the function of C_1 adjustment.

DESIGN CONSIDERATION: Single varicap CR_1 may exhibit non-linear transfer characteristics in comparison to push-pull arrangements.

Component values and parts list were not available at the time of publication.

SOURCE: William B. Secor
Radio Corporation of America
under subcontract to
Jet Propulsion Laboratory
(JPL–W00–016)

Voltage Generator Sweeps Oscillator Frequency Linearly with Time



APPLICATION: This is an example of a simple circuit that generates a voltage exponentially varying with time. When applied to a voltage-tuned oscillator, the output of which varies logarithmically with applied voltage, the resultant output is a linear frequency variation with respect to time. This circuit can be utilized for driving of frequency scanners.

CIRCUIT DESCRIPTION: With the sweep-direction flip-flop in the upward position, the diode switches are biased so that the output of the sweep-rate summing amplifier is connected directly to the sweep integrator through diode CR_1 and resistor R_1. The sweep-rate summing amplifier is driven by a signal proportional to the sweep integrator output voltage. The sweep-direction flip-flop is reversed at the end of each sweep by a pulse generator or other device (not shown). When the sweep direction is reversed, the sweep integrator is connected through diode CR_2 and resistor R_2 to the inverter whose voltage is the negative of the voltage from the summing amplifier, thus the sign of proportionality is reversed.

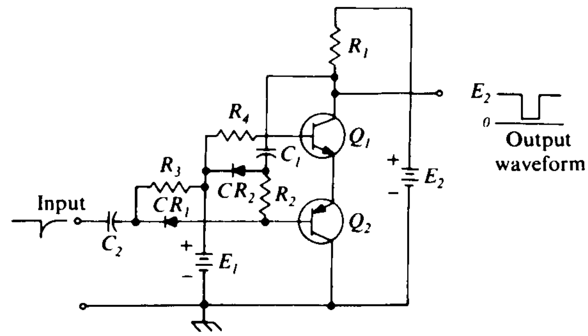
Component values and parts list were not available at the time of publication.

SOURCE: Melpar, Inc.
under contract to
Marshall Space Flight Center
(M–FS–219)
B64–10320

Section 3

MULTIVIBRATOR CIRCUITS

High Efficiency Monostable Multivibrator



APPLICATION: This monostable multivibrator circuit uses complementary transistors which are series connected to produce efficiency approaching 100 percent. This multivibrator has an output voltage equal to the power supply voltage and is well suited to applications where short pulses of high amplitude are required. The circuit can be used for pulse forming and timing circuits in radio, television, computers, and other instrumentation.

CIRCUIT DESCRIPTION: The multivibrator is triggered by a negative pulse to yield a one-shot rectangular output wave of an amplitude and duration determined by the constants built into the circuit. This form of one-shot pulse output is similar to that used in vibrating diaphragm pressure cell systems.

In this circuit, both transistors Q_1 and Q_2 are normally cut off because no voltage appears between their bases. A negative pulse is applied at the input, passing through capacitor C_2 and diode CR_1 to the base of Q_2, causing Q_2 *to* conduct. Since the emitters of Q_1 and Q_2 are interconnected, the voltage at this point is reduced, causing Q_1 to begin conducting. This causes current to begin flowing through R_1 producing a positive feedback due to the voltage drop attendant to the increase in current. The circuit quickly saturates and remains saturated until C_1 is discharged through R_2 (C_1 and R_2 determine the pulse duration). This removes the bias current from Q_2 at which point the reverse action occurs leaving the circuit in a cut-off state. Recovery of the circuit is accomplished by charging C_1 through R_1 and CR_2.

This circuit has a significant advantage over other multivibrators. A conventional multivibrator makes comparatively inefficient use of power because much of it is used to maintain the circuit in readiness, whereas in this circuit, the power consumed in the load is the only power used except for a very small amount consumed in the base circuit of Q_2 during switching. Stand-by power is zero even though the circuit is ready to respond at all times.

Another advantage to the reduction is the effective collector shunt capacity, by series connection of Q_1 and Q_2, which contributes to the speed of response of the circuit and allows the shortest possible rise and fall time of the output waveform.

DESIGN CONSIDERATION: This circuit can also be applied to a bistable multivibrator. It operates in a manner similar to the monostable with the exception that after the change from the non-conducting state to the conducting state, recycling does not occur until a negative pulse appears at the reset terminal. This circuit would contain fewer components than a conventional bistable multivibrator.

Typical circuit elements and component values include:

E_1	2.0 V
E_2	20.0 V
Q_1	2N647
Q_2	2N1131
CR_1, CR_2	300 mA
R_1	1K
R_2	4.7K
R_3	10K
R_4	22K
C_1	220 pF
C_2	100 pF

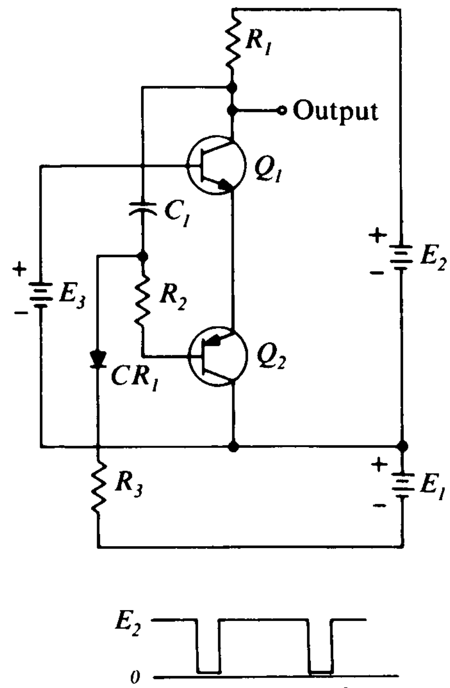
SOURCE: Robert Munoz
Ames Research Center
(ARC–24)

High Efficiency Astable Multivibrator

APPLICATION: This astable multivibrator circuit produces waveforms of high harmonic content such as rectangular waveforms, square waves, and trapezoids. Output dissymmetry is possible to a high degree. The circuit can be used in pulse forming, timing, and instrumentation applications.

CIRCUIT DESCRIPTION: This astable multivibrator circuit is self-starting. The circuit recycles when capacitor C_1 is discharged through diode CR_1, resistor R_3 and thereby allowing current to flow through resistor R_2 from the base of transistor Q_2 to start the generation of another pulse. The output interval is regulated by the time constant R_2, C_1 and the time between output intervals is regulated by the time constant R_3, C_1. Since R_2 may be very small and R_3 very large without affecting the circuit adversely, a high degree of dissymmetry in the output is possible. This dissymmetry is very limited in a conventional astable multivibrator due to the collector recovery time being small.

This circuit has an efficiency of approximately 100 percent, and the series arrangement of transistors Q_1 and Q_2 allows a reduction in effective collector capacity which improves the speed of response and allows the shortest possible rise and fall times in the output waveform.



Output waveform

DESIGN CONSIDERATION: Current flows only during the interval of output pulse generation.

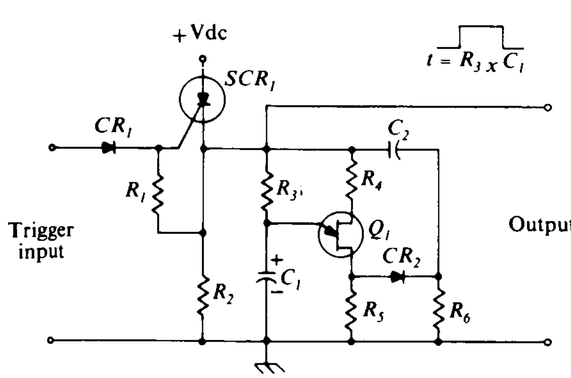
Component values and parts list were not available at the time of publication.

SOURCE: Robert Munoz
Ames Research Center
(ARC–24)

Ultra-Long Monostable Multivibrator

APPLICATION: This monostable multivibrator circuit is designed to provide a highly efficient means for generating timing intervals. It is a simple, reliable circuit which features an immunity to power supply transients and could be used in control mechanisms.

CIRCUIT DESCRIPTION: The trigger pulse fires the silicon-controlled rectifier, SCR_1, developing a voltage at the cathode which serves as both an output and as bias for unijunction transistor Q_1.



Capacitor C_1 charges through resistor R_3 to a point where the voltage across C_1 is equal to the Q_1 peak voltage. Q_1 fires and C_1 discharges through the emitter-base one junction and resistor R_5. The voltage pulse developed across R_5 passes through diode CR_2 and capacitor C_2, adds to the cathode pulse of SCR_1 and turns it OFF.

The duration of the output pulse from the SCR_1 cathode is determined by the time constant $R_3 \times C_1$. With proper components, this circuit will produce output pulses in the range of from 10 milliseconds to 60 seconds. The circuit is free from disturbance by transients in the power supply and operates at increased efficiency when heavily loaded. The illustrated circuit has driven loads up to 150 mA over a temperature range of -30 to 80° C.

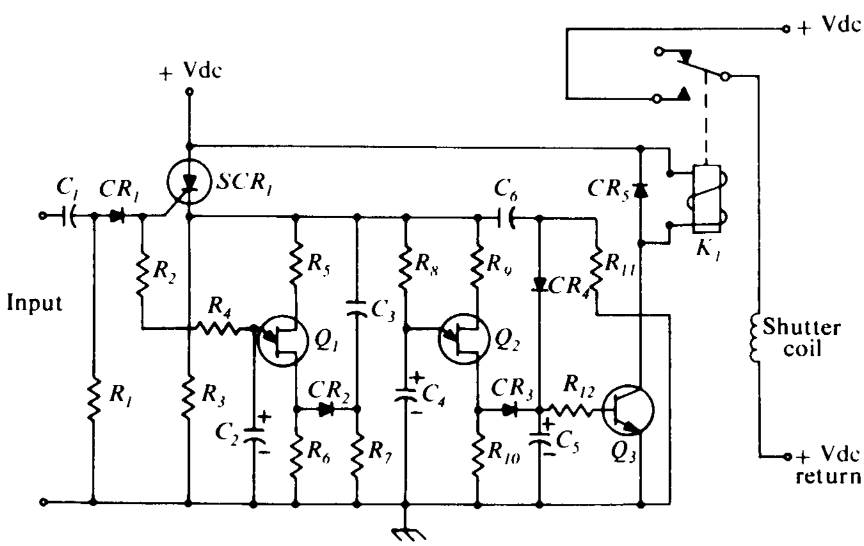
DESIGN CONSIDERATION: The time constant components, R_3 and C_1, must be chosen to accommodate the load being driven by the output. Sufficient time must be allowed to perform the required function before *SCR* turns off.

Typical circuit elements and component values include:

Q_1	2N1671B
SCR_1	2N886
CR_1, CR_2	1N645
C_1	100 μF
C_2	0.1 μF
R_1, R_2	4.7K
R_3	470K
R_4, R_5	100 Ω
R_6	22K
Output Pulse	50 seconds

SOURCE: Justin C. Schaffert and Norman E. Goldman
Goddard Space Flight Center
(GSFC-34A)
B65-10011

Multipulse Generator



APPLICATION: This multipulse generator circuit can be used in control circuitry where pulse generation in the range of 150 milliseconds are required, such as a shutter system used to protect an optical system from excess light.

CIRCUIT DESCRIPTION: In this circuit the trigger pulse through capacitor C_1 and resistor R_1 triggers the silicon-controlled rectifier SCR_1 turning it ON.

Capacitors C_2 and C_4 start to charge, through resistors R_4 and R_8 respectively, toward the SCR_1 cathode voltage. The constant of $R_4 \times C_2$ is approximately twice that of $R_8 \times C_4$. When the emitter of unijunction transistor Q_1 reaches its peak, C_2 will discharge through resistor R_6. The pulse across R_6 is coupled through diode CR_2 and added to the cathode voltage of SCR_1 which back biases SCR_1, thereby reducing its current below its holding value and turning it OFF. During this interval, the emitter of unijunction transistor Q_2 has reached its peak twice and C_4 has discharged through resistor R_{10} twice. Since the cathode voltage of SCR_1, toward which C_4 has been charging, is no longer existent, the relaxations stop.

The pulses generated across R_{10} charge capacitor C_5 through the impedance level of diode CR_3 and base one of Q_2. These pulses saturate transistor Q_3 when coupled to its base through resistor R_{12}. C_5 discharges through R_{12} and the base-emitter junction of Q_3.

The relay closes when Q_3 saturates. The duration of the closure is no longer than that afforded by the time constant $R_{12} \times C_6$ due to the hysteresis of the relay K_1 which effectively adds to this time constant so that K_1 is held closed for approximately 150 milliseconds.

The quiescent current is the leakage current of SCR_1. No temperature compensation is required to maintain the required pulse over a design temperature range of $-10°$ to $+60°$ C.

DESIGN CONSIDERATIONS: The sharp rise of the cathode voltage SCR_1 is differentiated by $R_{11} \times C_6$ and charges C_5 through CR_4. The time constant of $R_{11} \times C_6$ is chosen so that first relay closure is equal in time to those coupled from R_{10} through CR_3. Time constants of $R_4 \times C_2$ and $R_8 \times C_4$ are chosen so that the pulses generated at C_5 are spaced approximately 150 milliseconds apart.

Typical circuit elements and component values are as follows:

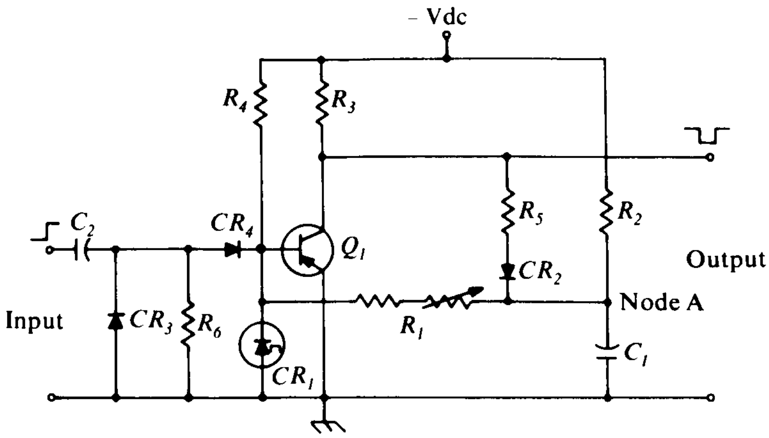
Supply	+ 20 Vdc
SCR_1	2N886
CR_1 through CR_5	1N645
K_1	BR5–1K
Q_1, Q_2	2N1671B
Q_3	2N930
C_1	0.01 μF
C_2, C_4	10 μF
C_3	0.1 μF
C_5	2.7 μF
C_6	1 μF
R_1	100K
R_2	2.2K
R_3	4.7K
R_4	68K
R_5, R_6, R_9, R_{10}	100 Ω
R_7	10K
R_8	33K
R_{11}	3.3K
R_{12}	27K

SOURCE: Justin C. Schaffert and
Norman E. Goldman
Goddard Space Flight Center
(GSFC–34A)
B65–10011

Monostable Multivibrator Circuit Using Tunnel Diode

APPLICATION: This circuit can be used in a variety of digital systems to improve fast response times and reliability. Specific applications would include computers, switching equipment, and instrumentation.

CIRCUIT DESCRIPTION: With the multivibrator circuit in its stable state, the tunnel diode CR_1 conducts and the transistor Q_1 is saturated. A positive trigger pulse fed into the input will cause CR_1 to switch to a low-



voltage state and to switch off. This initiates a quasi-stable state, the duration being controlled by the variable resistor R_1 and capacitor C_1.

With CR_2 back-biased and exhibiting a high impedance to node A, C_1 will begin to seek the steady state voltage where the low voltage resistance of CR_1 is approximately 50 ohms. Node A can be considered a changing voltage source for the supply of current to CR_1. Current through resistor R_1 is insufficient to supply the necessary switching current to CR_1. When the sum of the two currents from point A and R_1 peaks, diode tunneling process is initiated and CR_1 switches to the ON state. Voltage across CR_1 is impressed across the base-to-emitter of Q_1 causing it to switch to its saturated state, thus terminating the quasi-stable state of the multivibrator. C_1 will then discharge through Q_1 and the low impedance of CR_2, which is now forward-biased completing the transition back to the steady-state condition necessary before a new quasi-stable period can be initiated.

DESIGN CONSIDERATION: The use of a tunnel diode in this circuit makes it possible to exceed the performance of present multivibrators in two respects: (1) the rise time of the output voltage, less than 0.2 microsecond, is made independent of the capacitor used in the time delay and (2) the usable duty cycle can be raised from 65 percent to approximately 95 percent.

Typical circuit elements and component values include:

Supply	− 9 Vdc
Q_1	2N1500
CR_1	1N2940
CR_2, CR_3, CR_4	1N270
R_1	510 plus 10K Pot.
R_2	5.1K
R_3	1.0K
R_4	15K
R_5	100 Ω
R_6	8.2K
C_1	0.1 μF
C_2	250 pF

SOURCE: Paul Heffner
Goddard Space Flight Center
(GSFC–132)
B63–10603

Temperature-Sensitive Network Drives Astable Multivibrator

APPLICATION: This is a simple circuit technique consisting of two zener diodes and five resistors providing critical temperature stabilization of astable multivibrators. No stable square wave output of this circuit can be utilized for triggering of other circuits.

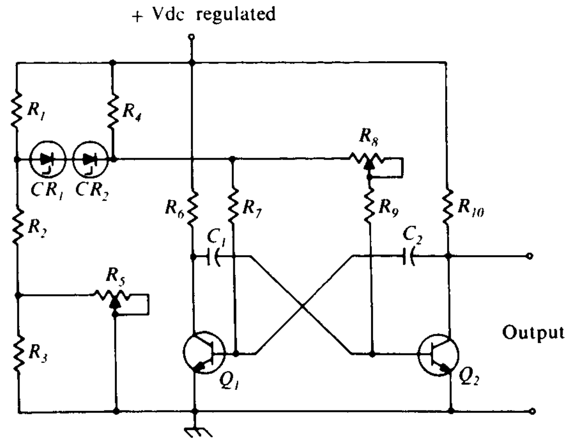
CIRCUIT DESCRIPTION: To provide multivibrator driving voltage, two zener diodes, CR_1 and CR_2, are referenced to a point held relatively stable at approximately half the supply voltage by resistors, R_1 and R_2, which serve as a conventional voltage divider. Working together, the two zener diodes provide a voltage which, when referenced to ground, is inversely proportional to temperature because the zener diodes have a breakdown voltage that is inversely proportional to temperature.

This circuit, with proper selection of components, can yield an output square wave at 2400 cps varying from 2398.5 to 2401.1 cps over a temperature range of $-10°$ to $+40°$ C. With adequate shielding of the zener diodes, the circuit may provide an output stability within 0.2 cps.

DESIGN CONSIDERATION: Potting of the zener diodes can further improve regulation of the output.

Typical circuit elements and component values include:

Supply	+ 18 V
Q_1, Q_2	2N930



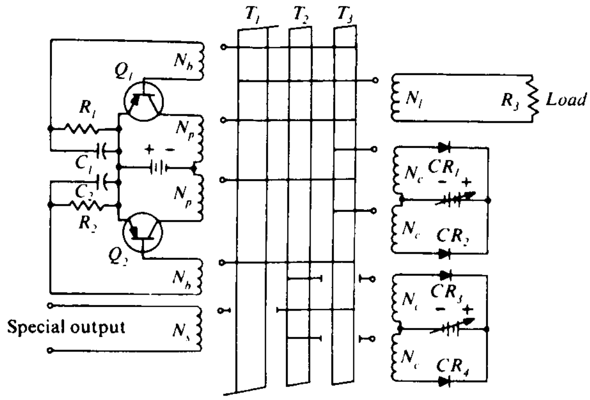
CR_1, CR_2	65060
R_1	8.25K
R_2	5.11K
R_3	2.87K
R_4	5.11K
R_5	2K
R_6	13.3K
R_7	432K
R_8	50K
R_9	392K
R_{10}	13.3K
C_1	1000 pF
C_2	1000 pF

SOURCE: Charles R. Wolfson
Radio Corporation of America
under contract to
Goddard Space Flight Center
(GSFC-137)
B63-10609

Magnetic-Coupled Multivibrator

APPLICATION: The characteristics obtainable by this multiple core transformer circuit may be advantageous in power oscillators in which the output frequency must be controlled electrically as part of certain feedback control systems. It may also find use in non-linear magnetic circuitry requiring a constant frequency source of ac voltage, and in instrumentation circuits using voltage-to-frequency conversion.

CIRCUIT DESCRIPTION: The circuit consists of a saturable transformer containing a main square-loop core and an auxiliary or control



square-loop core. The rate at which the main core swings from one saturation level to another is the transformer output frequency. The auxiliary core is arranged so that within certain limits, it can either increase or decrease the swing rate of the main core, thereby indirectly controlling the transformer output frequency.

A variable dc control voltage is applied externally to the auxiliary core winding and a switching circuit is connected to the input of the transformer. The switching circuit is arranged so that each time the main core saturates, the input voltage to the transformer reverses polarity. Under these conditions, the instant the main core saturates, the input voltage immediately attempts to saturate it in the opposite direction. However, the time required for the main core to react is determined by the level of the dc voltage applied to the auxiliary core. Thus, the output frequency of the transformer is determined by the magnitude of the control voltage.

DESIGN CONSIDERATIONS: A variety of operational characteristics can be achieved through various arrangements of cores and external circuits; such as output frequency decreasing with increasing control voltage, or output frequency increasing with increasing control voltage. In the circuit as shown, with two control voltages applied to separate auxiliary cores, the output frequency will vary as a function of the sum of control voltages.

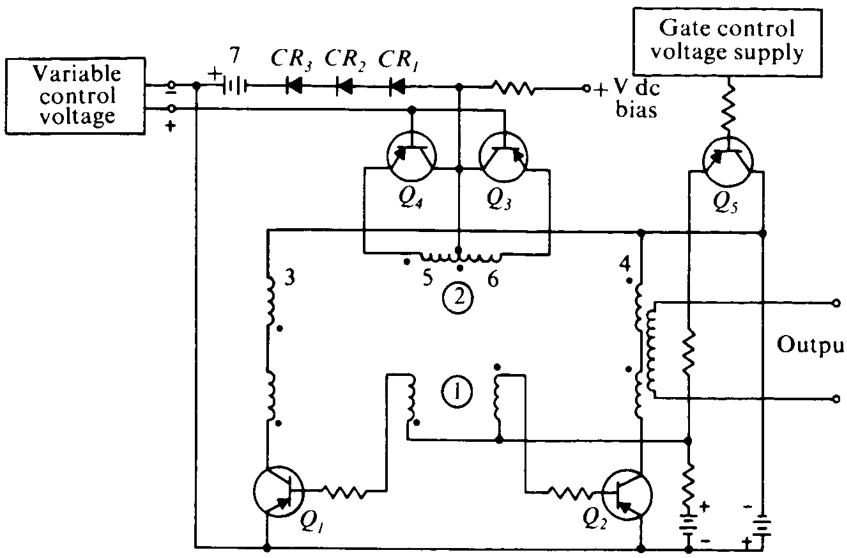
The special output winding included in the circuit provides a square-wave output with amplitude proportional to the sum of the dc control voltage. This output is isolated from both the supply and control voltages, and can be rectified for a dc monitoring signal or for other purposes.

Typical circuit elements and component values include:

T_1, T_2, T_3	Magnetics, Inc., No. 51026–2A, Orthonol, ID 1.0, OD 1.5, Ht 0.375 inch
N_p, N_L, N_c, N_s	35 turns of No. 24 wire
N_b	10 turns of No. 24 wire
Q_1, Q_2	Texas Instruments, Inc., 2N1045
CR_1, CR_2, CR_3, CR_4	General Electric Co. 1N539
R_1, R_2	270Ω
R_3	50Ω, resistive
C_1, C_2	0.2 μF

SOURCE: Robert W. Sterling, Edward T. Moore and Thomas G. Wilson
Duke University under contract to Goddard Space Flight Center
(GSFC–183)
B65–10119

Variable Frequency Magnetic Multivibrator



APPLICATION: This variable frequency control circuit operates in a full wave fashion rather than only over a portion of the multivibrator cycle of operation. The result is greater stability of operation in the low end of the multivibrator operating frequency and rejection of undesirable high frequency modes. This circuit can be incorporated in devices using clocks, synchronous motor control, stable square wave variable signal generators, test instruments, power generation control, matching magnetic bearing devices, and radio and television communications.

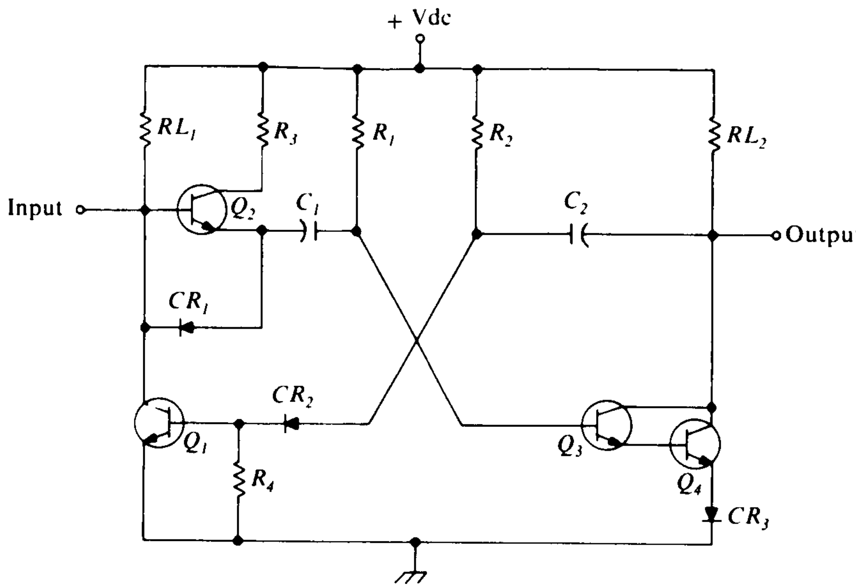
CIRCUIT DESCRIPTION: This multivibrator circuit includes an uncontrolled magnetic core 1 and a controlled magnetic core 2. A pair of conductive loops 3 and 4, each consisting of drive windings for cores 1 and 2 and one of the controlled transistor switches Q_1 and Q_2, provide the necessary alternate mode of operation for the multivibrator. The frequency is controlled by a circuit which consists of a full wave voltage limiter arrangement of transistors Q_3 and Q_4 and windings 5 and 6. The operation of the voltage limiter is controlled by the level of the variable control voltage. Changes in magnitude of this variable control voltage change the operating frequency of the multivibrator. An electronic gate is included for starting and stopping the multivibrator, and a temperature compensation network consists of diodes CR_1, CR_2, and CR_3. The circuit has a fixed bias potential 7 and a positive bias supply.

DESIGN CONSIDERATION: This circuit incorporates all static elements and is insensitive to wide changes in power supply potential or temperature variations. Stable square-wave output is provided over a wide frequency range.

Component values and parts list were not available at the time of publication.

SOURCE: Stephen Paull
Goddard Space Flight Center
(GSFC–AE–21)
B65–10124

High Duty Cycle Multivibrator Circuit



APPLICATION: This is an example of a simple transistorized circuit which provides highly asymmetrical multivibration pulse width ratios for timing circuits. The circuit features capabilities of pulse widths of 1 microsecond at a pulse rate frequency of 250 pulses per second. With an asymmetrical ratio of 13,000:1, operation should be continuous and waveforms at all important points excellent.

CIRCUIT DESCRIPTION: By adding transistor Q_3 to a normal astable multivibrator circuit, the effective β of transistor Q_4 is raised by the β of Q_3 allowing resistor R_1 to be raised by the same factor. Adding transistor Q_2 reduces the recovery time by a factor of β. Therefore, the maximum asymmetrical ratio is greater by a factor of β^2.

CR_1 is added to provide a discharge path from C_1 when Q_1 turns on. R_3 is added to limit the surge current, while C_1 is recharging below the maximum rated collector current.

DESIGN CONSIDERATION: Similar techniques can be applied to monostable multivibrators but with added capacitor and diode circuitry. Full supply voltage must be used to start operation.

Component values and parts list were not available at the time of publication.

SOURCE: Richard Alvin Tracy
Westinghouse Electric Corporation
under contract to
Manned Spacecraft Center
(MSC–67)

Section 4

POWER SUPPLY AND RELATED CIRCUITS

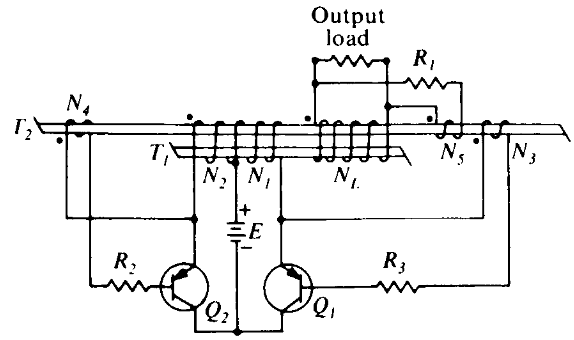
Transistorized DC to AC Converter

APPLICATION: This converter circuit makes use of transistors and a square-loop core in such a manner as to convert dc power to ac power very efficiently. The circuit reduces high switching currents and features improved efficiency and reliability. The circuit can be used in switching frequency generators and in both dc to dc and dc to ac converter applications.

CIRCUIT DESCRIPTION: In this circuit T_1 is a square-loop core and transistors Q_1 and Q_2 are PNP switch transistors. The ratio of winding N_5 to winding N_L is greater than unity.

The operation of this circuit during one cycle is as follows: With Q_1 conducting, Q_2 non-conducting and both cores unsaturated, a voltage is impressed across the winding N_1. A voltage will therefore be induced in winding N_L. This voltage is applied to the load and also causes a current to flow through resistor R_1 and winding N_5 in such a direction that the flux in core T_2 moves in a direction opposite to that of the flux in core T_1. The rate of change of flux in core T_2 induces voltages in winding N_3 and N_4 of such a polarity that current is caused to flow through the emitter-base junction of Q_1 causing it to remain ON and causing a reverse voltage to be applied to the emitter-base junction of Q_2.

When core T_1 saturates, the flux movement in T_2 will abruptly reverse direction and Q_1 will be quickly turned OFF and Q_2 will start to conduct. Since the circuit is symmetrical, Q_2 will continue to conduct until core T_1 again saturates. The circuit thus operates as an oscillator with a square-wave output. Oscillations start spontaneously when the dc voltage is applied.



DESIGN CONSIDERATIONS: Switching is initiated without the necessity of large currents existing in windings N_1 or N_2. Transients in the output voltage are greatly reduced. If a large output voltage is desired, N_L must contain a large number of turns. An additional winding, encircling both cores, to which N_5 can be connected instead of to the load winding may be preferred.

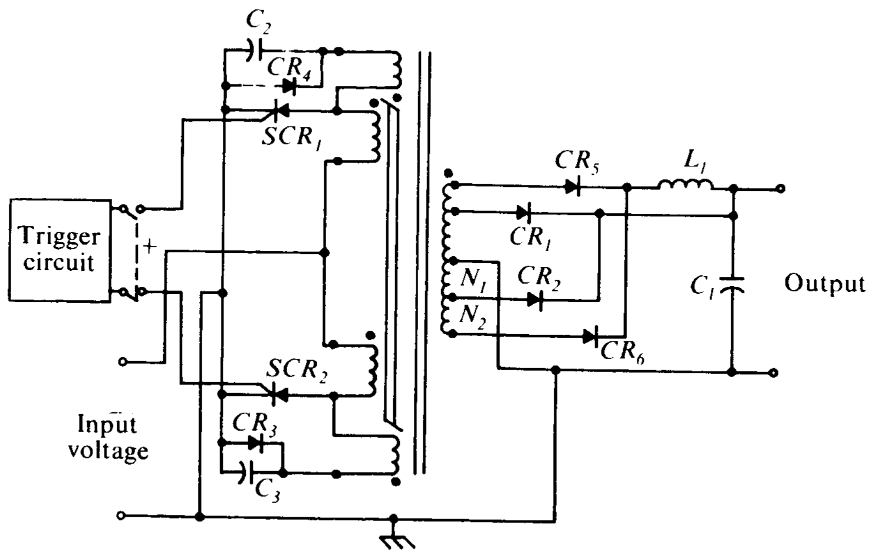
Component values and parts list were not available at the time of publication.

SOURCE: Edward T. Moore and
Thomas G. Wilson
Duke University
under contract to
Goddard Space Flight Center
(GSFC–70)

Circuit for Controlling Transients in SCR Inverters

APPLICATION: This is an example of a simple, effective circuit for eliminating starting difficulties in SCR (silicon controlled rectifier) dc to dc converters by providing a full-wave rectified output that is applied to an LC (inductive-capacitive) filter. The circuit can be used in various applications of parallel inverters using SCR's.

CIRCUIT DESCRIPTION: The circuit has, in addition to a center tap, two other taps on the output winding of the inverter. On starting, or



under transient loads, the two additional taps deliver power through diodes CR_1 and CR_2 without requiring quenching of SCR currents appreciably in excess of normal starting load current.

The converter can be started when the voltage across the filter capacitor C_1 is initially zero, with the first triggering pulse directed to the gate of SCR_1. When this SCR turns on, a large current will be initiated in the circuit consisting of winding N_1, diode CR_2, and capacitor C_1. C_1 will be quickly charged through CR_2 to a lower voltage than that appearing across the combined windings N_1 and N_2. Because of the low transient impedance of this "quick-charge" circuit, it is possible to complete the charging of C_1 so that the current through SCR_1 at the moment of quenching will nearly equal normal load current. As the current in the inductor L_1 increases, the voltage across C_1 rises to its steady state value and renders CR_1 and CR_2 nonconductive.

Excessive starting current transients through the SCR's are prevented by appropriately positioning the two off-center taps on the inverter, or by inserting small resistors.

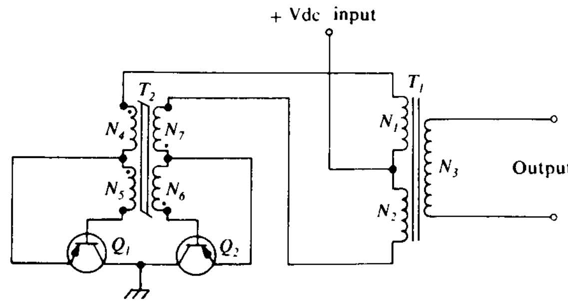
DESIGN CONSIDERATION: The circuit eliminates the effects of large transient dips in the load voltage. CR_1 and CR_2 become conductive as the output voltage drops, the reverse voltage across these diodes disappears and C_1 tends to offset transients.

Component values and parts list were not available at the time of publication.

SOURCE: Edward T. Moore and
Thomas G. Wilson
Duke University
under contract to
Goddard Space Flight Center
(GSFC-120)
B63-10600

Low Input Voltage DC to AC Converter

APPLICATION: This is an example of a dc to ac converter which is particularly suited for operation with a very low input voltage. Reliability is improved by eliminating current surges through the transistors. Efficiency is maintained with variations in input voltage and load current.



CIRCUIT DESCRIPTION: The operation of this circuit as a self-oscillating current-feedback converter depends on the combined effects of three non-linear characteristics: (1) the current-voltage characteristic of the rectifying emitter-base junction of the transistors, (2) the current-voltage characteristics between the collector and emitter terminals of the transistors, and (3) the hysteresis loop of transformer T_2. Transformer T_1 serves merely as the output transformer for the converter. The two transistors in this circuit Q_1, Q_2 are alternately turned on and off to impress the input voltage first across turns N_1 and then across turns N_2 of the output transformer T_1, inducing a square wave of alternating voltage in the output turns of N_3. Switching of the transistors is caused by the cyclic saturation of the square loop core of transformer T_2.

Transformer T_2 and its windings is a sharply-saturable current transformer. With one transistor conducting and T_2 unsaturated, the load impedance limits the transistor collector current, and the base current is dictated by the turns ratio $N_4/N_5 = N_7/N_6$ of the current transformer. This ratio is chosen in accordance with the base-drive requirements of the transistors.

When transistor Q_1 is conducting with given values of collector and base currents, its emitter-to-base voltage drop appears across turns N_5 and establishes the rate-of-change flux in the core of transformer T_2. Transformer T_2 becomes saturated and decoupling takes place between turns N_4 and N_5. The base current to transistor Q_1 then decreases and Q_1 is turned off. Some energy is stored in the after-saturation of core of transformer T_2. This energy is returned to the circuit and transistor Q_2 is turned on. The circuit is self-oscillating and is symmetrical with events in alternate half cycles being complimentary.

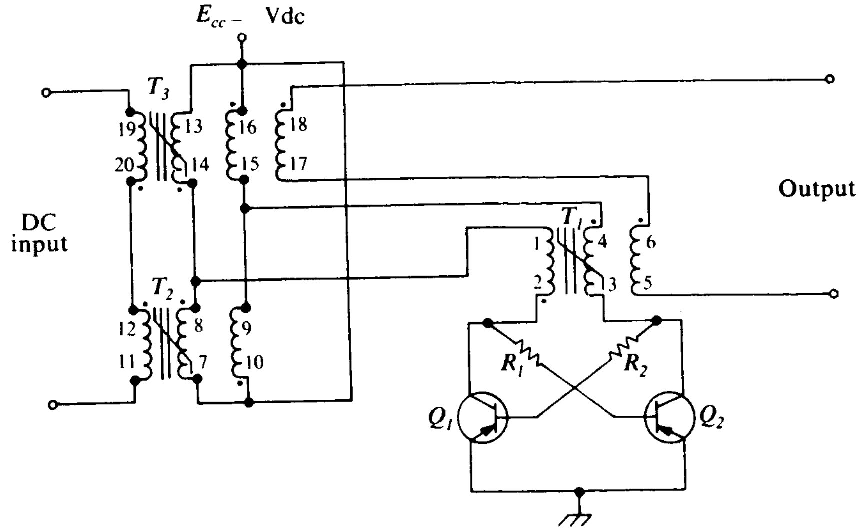
DESIGN CONSIDERATION: It is important to use closely matched transistors to avoid a loss in efficiency. Transformers T_1 and T_2 are hand wound on saturable toroid cores. Oscillating frequency is given by the relation $f = \frac{VBN}{4NAB_m} \times 10^8$ which is a function of the load current as effective VBE, and where $N = N_5 = N_6$, $A =$ the cross-sectional area of core T_2 in square centimeters, and $B_m =$ saturation flux density of core T_2 in gauss.

Typical circuit elements and component values include:

Q_1, Q_2	Motorola XP726
T_1	Magnetics, Inc., No. 52001–4A; ID 1.5, OD 2.5, Ht 0.5 inch
T_2	Magnetics, Inc., No. 51395–2A; ID 1.08, OD 1.26, Ht 0.08 inch
N_1, N_2	10 turns of 15 strands of No. 18 wire
N_3	192 turns of No. 18 wire
N_4, N_7	5 turns of 15 strands of No. 18 wire
N_5	49 turns of No. 18 wire
N_6	50 turns of No. 18 wire
Load	Resistive

SOURCE: Edward T. Moore and
Thomas G. Wilson
under contract to
Goddard Space Flight Center
(GSFC–130)
B65–10178

Current to Frequency Converter



APPLICATION: This circuit features a three-core square-loop magnetic multivibrator with an operating frequency which depends on the value of a direct current being measured. This is an example of reliably converting dc to frequency for instrumentation or control purposes. The converter eliminates intermediate stages and provides current to frequency conversion in a single circuit. A possible application is a current measuring device in a satellite telemetering system, particularly for monitoring battery current drain.

CIRCUIT DESCRIPTION: Switching windings on core of transformer T_1 are connected in series with windings on cores of transformers T_2 and T_3. Transformer T_2 switching windings are connected in parallel with transformer T_3 switching windings. The series-connected control windings of transformers T_2 and T_3 are wound so that the input control current flowing in them opposes switching action in transformer T_2 when transistor Q_1 is conducting and opposes reset action in transformer T_3 when transistor Q_2 is conducting.

The rate of flux change in transformers T_2 and T_3 is determined by the input dc in the control windings. This affects the effective voltage across transformer T_1 windings and the time required for complete flux reversal in transformer T_1.

Multivibrator flip-flop action occurs when transformer T_1 saturates. Therefore, multivibrator frequency is a function of input control current and a square wave output of constant amplitude is obtained from the series-connected output windings on transformers T_1 and T_3.

DESIGN CONSIDERATION: Transformers T_1, T_2, and T_3 are hand wound on saturable toroid cores. Output frequency will normally not vary linearly for a wide range of current and temperature will affect frequency. Calibration will be required in actual application.

Component values and parts list were not available at the time of publication.

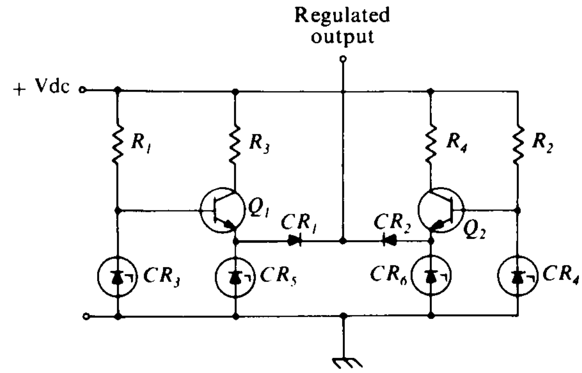
SOURCE: Stephen Paull
Goddard Space Flight Center
(GSFC–149)

Highly Reliable Regulated Voltage Supply

APPLICATION: This is an example of a transistor regulated dc power supply circuit which features high reliability through redundancy. The circuit may be considered fail-safe because if any single component fails, or if one of many multiple component failures occur, the regulated output will remain the same with none of the other elements being overstressed electrically as a result of the failure. The circuit can be utilized in power supplies for remote, unattended communications or data telemetry applications, such as relay stations or satellite equipment.

CIRCUIT DESCRIPTION: Zener diodes, CR_3 and CR_4, provide the desired regulated voltage at the emitters of transistors, Q_1 and Q_2. Diodes, CR_1 and CR_2, provide isolation of the two sides so that the higher of the two voltages present at the emitters will appear at the output. Thus, if one side shorts or opens, the output is unaffected by the failure. Zener diodes CR_5 and CR_6 are included as additional protection should CR_3 or CR_4 fail. Resistors, R_1 and R_2, provide the required drive to Q_1 and Q_2. Resistors, R_3 and R_4, are used to reduce the dissipation at the collectors of Q_1 and Q_2.

DESIGN CONSIDERATIONS: The value of R_1 and R_2 can be calculated by considering the drive required by Q_1 and Q_2 to supply the total current required by the subsystem. Each side should be capable of supplying this current, and the desired amount of bias current for CR_3 and CR_4.



The value of R_3 and R_4 can be calculated by considering the total current supplied by each transistor, the maximum allowable dissipation at the collectors, and the desired amount of bias current for CR_5 and CR_6.

Typical circuit elements and component values include:

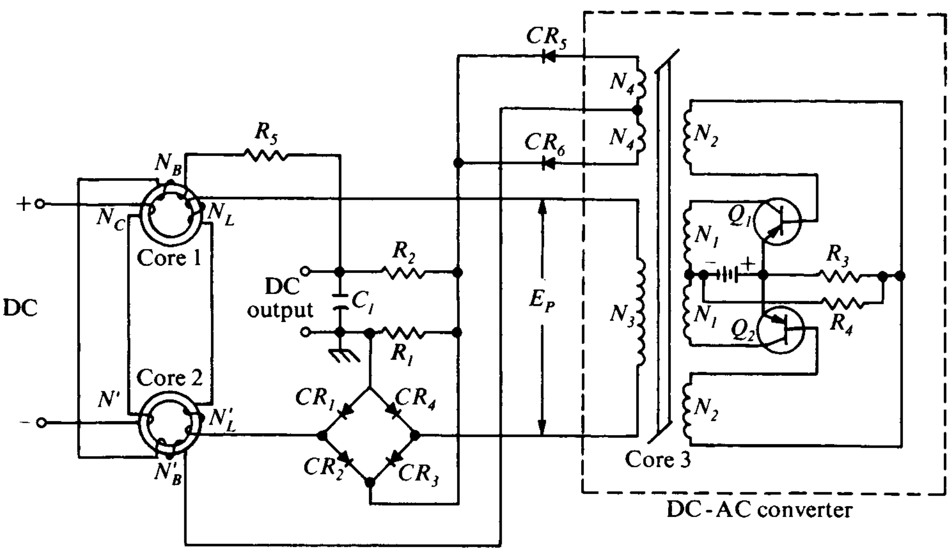
	6.8V Regulator	12V Regulator
Input Supply	+ 28 V dc	+ 28 V dc
Q_1, Q_2	DEP08B	DEP08B
CR_1, CR_2	1N645	1N645
CR_3, CR_4	1N756A	1N965B
CR_5, CR_6	1N3018B	1N2979B
R_1, R_2	4300 Ω, ½W	1600 Ω, ½W
R_3, R_4	910 Ω, 2W	300 Ω, 3W

SOURCE: James Blair
Radio Corporation of America
under contract to
Goddard Space Flight Center
(GSFC-192)

Magnetic Voltage and Current Monitor

APPLICATION: This circuit, comprised of a self-balancing magnetic amplifier using dc bias, can be used for measuring currents and voltages with a high degree of linearity and accuracy, with very low power consumption, and can find various uses in instrumentation design. Another is spacecraft applications where it is desired to monitor various voltages and currents.

CIRCUIT DESCRIPTION: This circuit is capable of accepting a dc or ac voltage or current



signal over a wide dynamic range and producing a dc voltage at its output proportional to the input with an accuracy of $\pm$ 0.5 percent. The circuit features the advantages of minimizing the variation in the rectifier reverse characteristics, the effects of supply voltage variations, and the effects of frequency variations. The general operation of this circuit is such that when the voltage E_p goes positive, core *1* is driven into positive saturation through load winding N_L and at the same time core *2* is driven into negative saturation through winding N'_L. This situation is reversed when voltage E_p goes negative. The effect of any discrepancy in the two core characteristics will tend to be reduced to a minimum. The bias current supplied from the power supply through resistors R_2 and R_5 is directly proportional to the voltage output. The quiescent current is that current which will flow in the output load windings N_L and N'_L when the control current flowing through control windings N_C equals zero. This quiescent current is controlled by the bias current flowing in the bias windings N_B and N'_B. These windings act as additional control windings to make the quiescent current practically independent over a voltage supply variation from $\pm$ 5 to $\pm$ 10 percent.

The circuit shown is designed for monitoring low currents. The transformer turns-ratio is selected for a low quiescent current in the load windings when the current in the control windings, N_C, is reduced to zero. To achieve the low quiescent current, windings N_L and N_B are made as large as possible and the ratio of load winding turns N_L is selected as follows: $N_L = N_C + N_B$. To establish the proper bias voltage, resistor R_5 is connected in series with the winding N_B. Resistors R_1 and R_2 form a voltage-mixing circuit. They are connected across the load winding of core *1* and core *2*, and capacitor C_1 is connected across the dc output to reduce the ripple.

To produce the driving voltage and frequency necessary to supply the magnetic amplifier, a dc to ac converter, using transistor switching and a square-loop magnetic core, giving a constant volt-second wave-form, is used.

To use this circuit as a voltage monitoring device, the same design as that used for low current monitoring will apply to voltage monitoring application. The ratio $N_C = N_B$ and $N_C + N_B = N_L$. To maintain the same output with an increased voltage input a resistor must be added in series with the control windings.

DESIGN CONSIDERATION: During the normal development of this circuit it will require balancing by adjusting the values of resistors R_1, R_2, and R_5.

Typical circuit elements and component values include:

Power Supply	+ 12 V dc
Cores *1, 2, 3*	5007–ID type
Q_1, Q_2	2N871
CR_1 through CR_6	1N252
R_1, R_2	4.5K (Nominal)
R_3	15K
R_4	68K
R_5	75K (Nominal)
C_1	0.47 μF
Input	0 to 5 A
Output	0 to 5 V dc

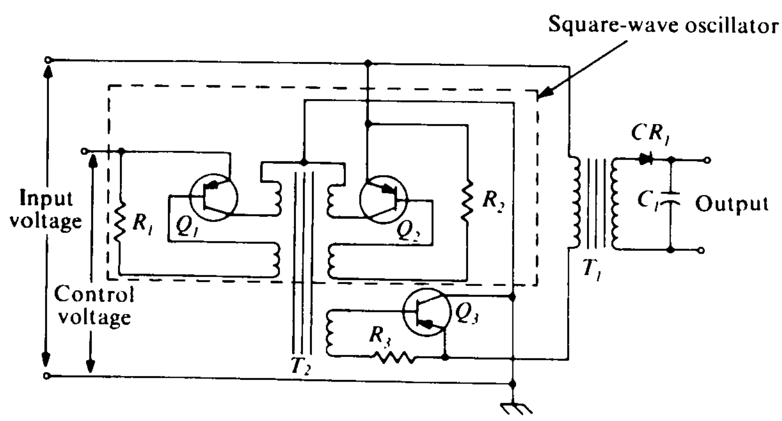
Winding turns of No. 39 wire:

N_C, N'_C	1
N_B, N'_B	3500
N_L, N'_L	3500
N_1	1080
N_2	100
N_3	1610
N_4	400

Note: The number of turns N_C varies inversely with the current to be monitored.

SOURCE: Warren R. Crocket
Goddard Space Flight Center
(GSFC–223)

Transistorized Converter and Regulator



APPLICATION: This is a transistorized regulator converter which is non-dissipative in operation and functions in an open loop through variable duty cycles. The circuit utilizes basic principles which fit a variety of circuit configurations for varying requirements such as fluctuating loads and selected power levels.

CIRCUIT DESCRIPTION: A square-wave oscillator that is essentially a magnetically-coupled multivibrator functions as a low power driver circuit that switches transistor Q_3 on and off. The time duration of alternate half cycles of the oscillations are not necessarily equal. The length of one half cycle is determined by the magnitude of the input voltage while the length of the alternate half cycle is determined by the magnitude of the control voltage. The relationship between the input voltage and the control voltage and the time duration of the alternate cycles produces the inherent open-loop regulation of this circuit.

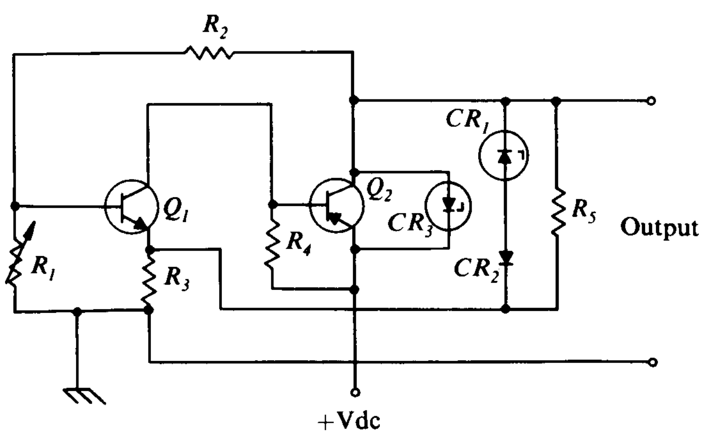
As Q_3 is alternately switched on and off, it causes the input voltage to be impressed across the primary winding of transformer T_1. With the control voltage held constant, the output voltage is also constant despite changes in the magnitude of the input voltage to the converter.

DESIGN CONSIDERATION: Transistors Q_1 and Q_2 should be selected for matching characteristics and some consideration should be made for the temperature effects on all transistors.

Component values and parts list were not available at the time of publication.

SOURCE: Duke University
under contract to
Goddard Space Flight Center
(GSFC-238)
B64-10305

Variable Voltage Supply Uses Zener Diode Reference



APPLICATION: This circuit uses a zener diode as a reference element to provide a stable variable reference voltage. It may be applied to low voltage power supplies.

CIRCUIT DESCRIPTION: Zener diode CR_1 is used as the reference element in this circuit. Voltage control is provided by a two-stage amplifier, consisting of transistors Q_1 and Q_2. The output voltage can be varied by selection of value for R_2, and is equal to $V_{out} = V_Z (1 + R_1/R_2)$ where V_z is the breakdown voltage of zener diode CR_1.

Zener diode CR_3 is used to start the circuit. The voltage drop across diode CR_2 must be larger than the collector-emitter voltage of Q_2. A positive feedback loop between the transistors is incorporated in the circuit, therefore, CR_3 is cut off when the circuit is ON.

Current flow through Q_1 and Q_2 is controlled by the setting of R_1. Increasing the resistance of R_1 increases the current flow through the transistors which, in turn, cause an increased current flow through zener diode CR_1 and resistor R_3.

The output voltage appears across the series connection of CR_1 and R_3. Since the characteristics of zener diode CR_1 are fixed, an increased output voltage can be obtained by increasing the voltage (IR drop) across R_3. This is accomplished by adjusting R_1. The voltage rise at the emitter of Q_1 limits the positive feedback and prevents unrestricted increase of the output voltage.

DESIGN CONSIDERATIONS: Diode CR_2 is included in the circuit to eliminate voltage dependence upon the emitter-base voltage of Q_1.

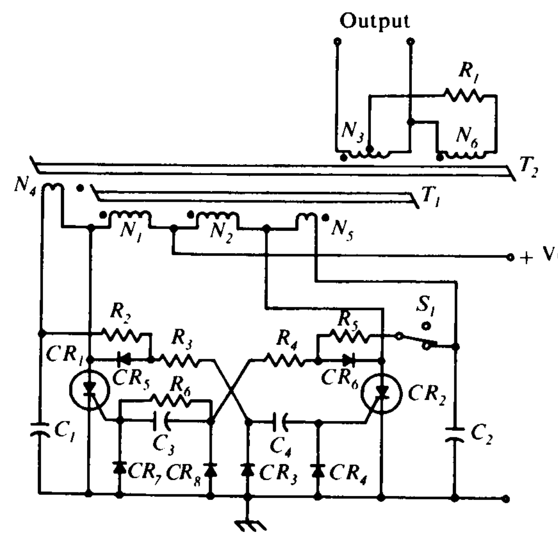
It may be omitted, if desired. The output voltage may be applied to an emitter-follower circuit to obtain higher operating currents.

Component values and parts list were not available at the time of publication.

SOURCE: R. C. Lavigne and L. L. Kleinberg
Goddard Space Flight Center
(GSFC–262)
B65–10097

DC to AC Converter Using Silicon Controlled Rectifiers

APPLICATION: This is a parallel inverter circuit using two silicon controlled rectifiers, CR_1 and CR_2. A non-linear transformer, having two square-loop cores, turns the SCR's OFF at the end of the desired interval of conduction. The circuit can be used to convert direct current to alternating current to provide enough power for portable equipment that normally operates on 110-volt ac, such as household appliances or on board a boat using an automobile or boat battery for power source. It can also be used for conversion of dc at one voltage level to dc at another voltage level.



CIRCUIT DESCRIPTION: The transformer in this circuit contains two square-loop cores. Core T_1 is the main power handling core. The magnetic properties of core T_1, along with the number of turns of the primary windings N_1 and N_2 and the magnitude of the dc source voltage, determines the length of the individual SCR conduction intervals. Core T_2 is effective during only a short portion of each cycle and can be much smaller in area than T_1. The primary windings N_1 and N_2 and the load winding N_3 encircle both cores. Windings N_4, N_5, and N_6 encircle only core T_2. The turns ratio $N_1 : N_4$, must be greater than unity.

A positive pulse is applied to the gate of CR_1 by closing switch S_1, thereby turning CR_1 ON. CR_2 is in the blocking state and core T_1 is saturated to the left. When CR_1 is turned ON, the direct voltage is impressed across winding N_1 and the flux in core T_1 begins to move to the right. A voltage of corresponding polarity is induced in the load winding N_3. When core T_1 saturates to the right, core T_2 becomes effective and voltages are induced in windings N_4 and N_5 causing CR_1 to be turned OFF.

While CR_1 is conducting, capacitor C_4 discharges through resistor R_3, diode CR_5, diode CR_4, and CR_1. When CR_1 begins to turn OFF, the voltage across the upper plate of C_1 immediately begins to rise, the left side of resistor R_3 becomes negative and current flows from right to left in R_3. Current continues to flow in this direction until CR_1 regains its ability to block forward voltage. When CR_1 reaches its blocking state, R_3 reverses direction and a positive current flows through R_2, R_3, capacitor C_4, and the gate-cathode path of CR_2. In this manner, the turning OFF of CR_1, after the necessary delay, causes CR_2 to turn ON thereby initiating the next half cycle. The events of each half cycle are complementary and the circuit is self-oscillating, with a square-wave output voltage. Opening switch

S_1 will cause oscillations to cease, with CR_2 being the last to conduct.

Capacitor C_3 is shunted by the high resistance of resistor R_6 to prevent the leakage current through CR_6 from charging C_3 to the source voltage.

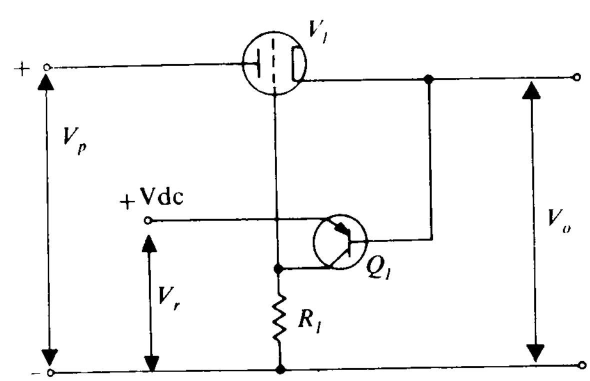
Circuit elements and component values for a typical circuit are as follows:

Input	+ 28 V dc
CR_1, CR_2	2N1772A
CR_3, CR_4, CR_5 CR_6, CR_7, CR_8	1N539
R_1	620 Ω
R_2, R_3, R_4, R_5	100 Ω
R_6	82 K
C_1, C_2	3.0 μF
C_3, C_4	0.1 μF
N_1, N_2	46 turns
N_3	200 turns, tap at 48 turns
N_4, N_5	22 turns
N_6	90 turns
T_1	3 stacked cores, each ID 1.250, OD 1.750, Ht. 0.250 inch
T_2	Single core, ID 1.250, OD 1.750, Ht. 0.250 inch Hi-Mu 80

SOURCE: E. T. Moore, T. G. Wilson and R. W. Sterling
Duke University
under contract to
Goddard Space Flight Center
(GSFC-A-6)

Hybrid Voltage Regulator Circuit

APPLICATION: This circuit features simplicity of design, making it readily adaptable to many applications where voltage regulation is required, such as a high quality laboratory power supply.



CIRCUIT DESCRIPTION: This circuit is designed so that the base-to-emitter voltage V_{be} (ratio of emitter reference voltage to output voltage) of transistor Q_1 is providing a high degree of output voltage accuracy, even with a large change in V_{be}. With small source impedance (V_r and V_o), resistor R_1 can be very large and the transistor voltage gain (A_v) will be very large (1000 or greater for a typical circuit) leading to two desirable effects.

1. Variations in V_p will be reduced by a factor approximately equal to A_v times the amplification factor of vacuum tube V_1. A value for this factor $\mu \times A_v$ would be very large (20,000 typical), therefore in variation V_p (main power source) will have extremely little effect on V_o.

2. The output impedance of the regulator will be very small. This impedance is approximately equal to the reciprocal of the product of A_v and the transconductance (gm) of V_1. This impedance $1/gm \times A_v$ might have a typical value 0.3 ohms or less at low frequency.

Since there are only two active elements in the regulator circuit and since the frequency response of V_1 will typically be much higher than that of Q_1, the circuit is quite stable.

DESIGN CONSIDERATIONS: When making additional refinements to the circuit, a condenser may be placed across the output in order to maintain the low output impedance of the regulator to the high frequencies at which the loop gain of the regulator is reduced. For a given desired V_o, R_1 can be chosen so that the maximum allowable collector-junction power dissipation will not be exceeded even if the collector-junction breaks down. If this cannot be done for a particular circuit or if it is desired to be very conservative, a zener diode (the zener voltage of which is less than the maximum transistor-collector-to-base voltage rating) may be placed between the emitter and the collector to prevent this breakdown of the transistor. A silicon diode may be added to protect the emitter-to-base junction of transistor Q_1 from damage which might occur if V_r went to zero and V_p did not.

Component values and parts list were not available at the time of publication.

SOURCE: Richard C. R. Bemis
Jet Propulsion Laboratory
(JPL-64)

Alternating Current Regulator

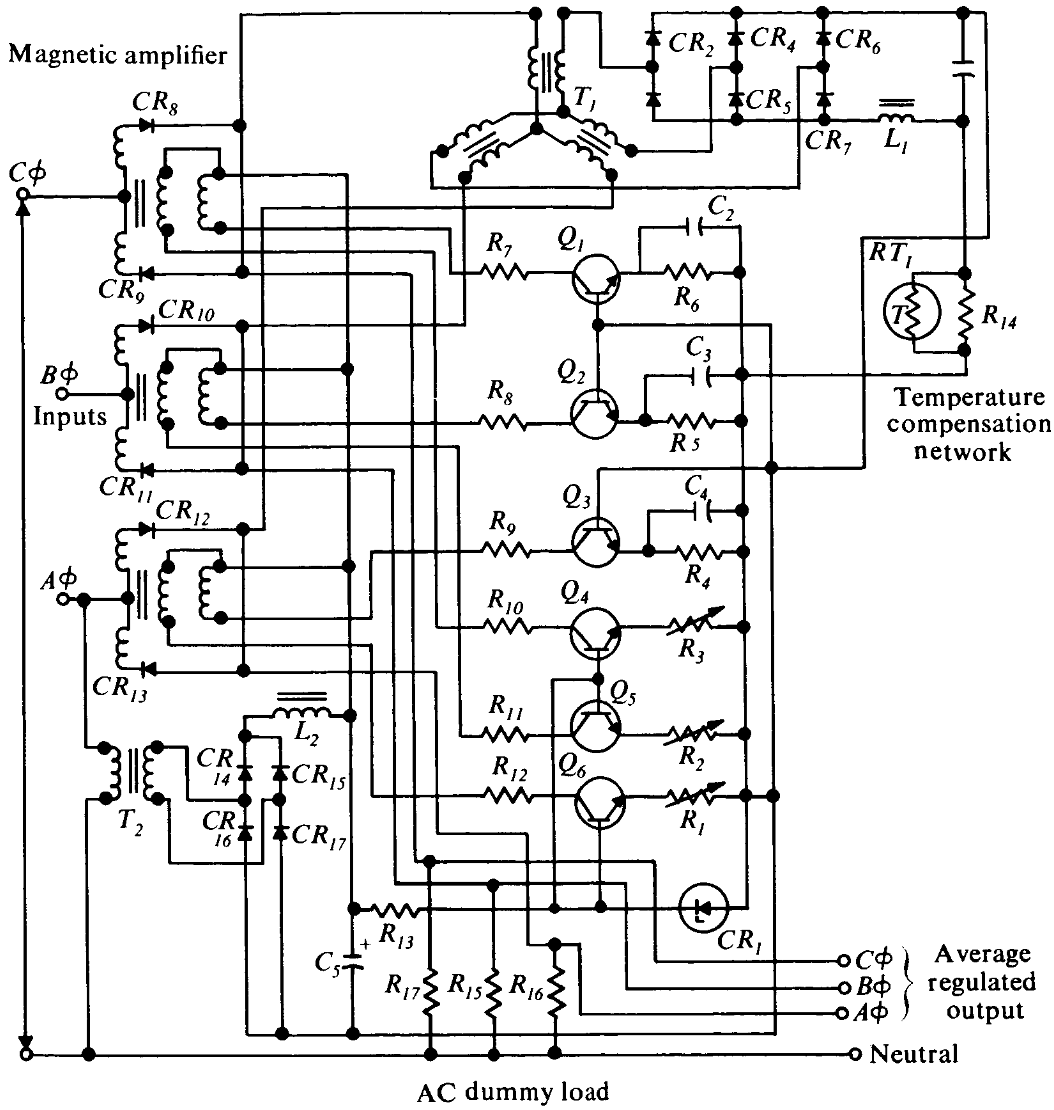
APPLICATION: This alternating current regulator circuit features light weight, relative simplicity and accurate response. It can be used in any voltage regulator application where wave shape is not a restraining factor. The circuit has power handling capabilities of up to 750 watts with an 85 percent efficiency, and temperature response is $\pm$ 3 percent drift over a range of $-40°$ to $+220°$ F.

CIRCUIT DESCRIPTION: Magnetic amplifiers are used as regulating elements in this circuit because of their ability to phase control voltage at high energy levels. Transformer T_2, with output rectified and filtered, provides source voltage for control and bias winding excitation. Transformer T_1, with associated rectifier-filter, senses the 3-phase average output voltage to provide the required control winding excitation to maintain constant output. Bias winding excitation is controlled by potentiometers R_1, R_2, and R_3. The bias point for each magnetic amplifier is set by sequentially adjusting potentiometers R_1, R_2, and R_3. The bias current offset requires large control currents which are less sensitive to small circuit variations, such as transistor gain versus temperature.

Transistors are used in the current mode to isolate winding impedance variations in the collector circuits and to restrict winding excitation variations to the small collector-emitter gain variations. Zener diode CR_1 was chosen as current reference for transistors Q_4, Q_5, and Q_6 because its temperature coefficient most nearly compensates that of the transistor base-emitter diode. It is necessary to add a thermistor circuit, RT_1, R_{14}, in the control feedback loop mainly to compensate the copper resistance variations of coil L_1.

Transient response is limited to one-half cycle since this time is required for source variations to be sensed. Further response delays are caused by L_1 and C_1 in the sensing filter and by the magnetic amplifier correction time. Capacitors C_2, C_3, and C_4 provide a lead network for compensation of the L_1, C_1 delay. Overcompensating with these capacitors will cause low damping and may lead to oscillation.

DESIGN CONSIDERATIONS: Loading effects are important when considering applications for this type of ac regulator. When numerous secondary voltages are required, transformer step-down is necessary. The secondary loading may consist of a wye-delta 3-phase transformer. It is important that the primary be a wye with a neutral connection so that any unbalance currents will have neutral return and not reflect back into the magnetic amplifiers. Wave shape distortion can be eliminated by providing separate cores for each phase of the step-down transformer.



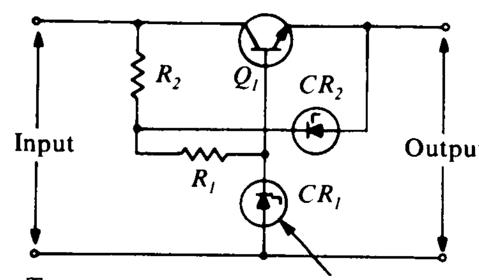
Typical circuit elements and component values are as follows:

Input	208 VAC, 3-phase, 400 cps	L_1	5 H, 10 mA
Q_1, Q_2, Q_3, Q_4, Q_5, Q_6	NPN	L_2	0.5 H, 100 ma
CR_1	SV808	RT_1	5K
CR_2, CR_3, CR_4, CR_5, CR_6, CR_7	1N647	C_1	0.47 μF, 400 V. dc
CR_8, CR_9, CR_{10}, CR_{11}, CR_{12}, CR_{13}	TR152/C	C_2, C_3, C_4	0.022 μF, 400 V dc
CR_{14}, CR_{15}, CR_{16} CR_{17}	1N647	C_5	13 μF, 100 V dc
		R_1, R_2, R_3	1.5K
		R_4, R_5, R_6	68K
		R_7, R_8, R_9, R_{10} R_{11}, R_{12}	2K
		R_{13}	3.3K, ½W
		R_{14}	5K
		R_{15}, R_{16}, R_{17}	1K, 25W

T_1	3ϕ, 1:1 3 ma/ϕ	SOURCE: Neil H. Herman and Donat A. A. Vincent Jet Propulsion Laboratory (JPL–262)
T_2	120:56.5 VRMS, 100 mA	

Voltage Regulator Circuit

APPLICATION: This circuit can find use in low voltage regulated dc power supplies. It permits the use of a low voltage zener diode with resultant low power dissipation. This circuit regulates the output to 25 millivolts against ±10 per cent line changes and maintains the output voltage to within ± 20 millivolts over the temperature range of − 10° to + 65° C.



Temperature-compensated reference

CIRCUIT DESCRIPTION: The voltage regulator is an emitter-follower (Q_1) using zener diode CR_1 to maintain a base reference. In this type of regulator, the zener diode current is ordinarily supplied by means of a resistor, R_1, connected to the unregulated supply voltage. Using this method, two problems arise: the reference voltage changes as the line voltage changes and the temperature-compensated zener reference is compensated at only one temperature.

The problems are solved by utilizing a temperature compensated reference and employing a second zener diode, CR_2, to maintain a nearly constant current through the reference. Zener diode CR_2 is returned to the regulated output voltage of emitter follower Q_1, rather than the common line. Since CR_2 is a low voltage zener, the current passed is delivered to the output load without increasing the primary line current. As the line voltage is increased, the zener current increases, thereby lowering the current through regulator transistor Q_1. The effect limits the power dissipated in the transistor.

DESIGN CONSIDERATION: The circuit used with a + 28 V dc, ± 10 percent input, would require a resistance of 2.8K for R_1 and 1K for R_2. With a type 2N910 for Q_1, CR_1 would be a 20 V rated reference zener and CR_2 a 3.3 V rated zener. This would result in a + 19.5 V dc regulated output applied to the load.

Component values and parts list were not available at the time of publication.

SOURCE: Larry W. Moede
Datametrics Corporation
under subcontract to
Jet Propulsion Laboratory
(JPL–W00–030)

Current Limiting Circuit

APPLICATION: This circuit can be used in applications where current limiting is desired or required, for example, as a driver for variable loads such as magnetic core shift registers or dc motors.

CIRCUIT DESCRIPTION: Ideally, current limiters are two-terminal devices with characteristics which are the current analog of those of a zener diode. The ideal limiter has a nominal voltage drop, V_o, across it for all currents below some value of limit current, I_L, such as an ideal diode. Once I_L is reached, however, it is prevented from increasing any further. The basic limiter circuit is shown in sketch a. The purpose of diodes CR_1, CR_2, and CR_3 is to provide a fixed voltage drop, V_{23}, which is independent of the current through them. Zener diodes may be used in this application. The relationship may be shown as follows:

$$I_L = I_L\ (V_{13}, V_{23}, R_1, R_2, \beta),$$

where $(1+\beta)\ I_b = I_e$.

$$I_e = \frac{V_{23} - V_{be}}{R_2} = (1+\beta)\ I_b \qquad (1)$$

$$I_L = I_e + I_d \qquad (2)$$

$$I_d = I_1 - I_b \qquad (3)$$

$$\therefore I_L = \beta I_b + I_1 \qquad (4)$$

$$I_L = \frac{V_{13} - V_{23}}{R_1}$$

$$I_L = \beta I_b + \frac{V_{13} - V_{23}}{R_1}$$

or

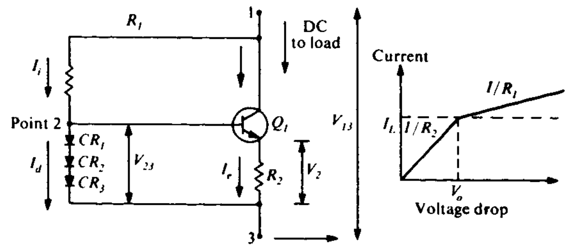
$$I_L = \frac{\beta}{1+\beta} \cdot \frac{V_{23} - V_{be}}{R_2} - \frac{V_{23}}{R_1} + \frac{V_{13}}{R_1} \qquad (5)$$

Equation 5 has only one variable term, V_{13}. All other terms are essentially constants. Current I_L may be made as insensitive as desired to variation in V_{13}, by increasing the value of R_1, causing an increase in the minimum voltage V_{13} necessary to maintain I_L, and hence a greater dissipation of power in the device and having characteristics shown in sketch b. For current below I_L, the drop across V_{13} varies with current as $1/R_2$. Once I_1 is reached, the current I through the limiter grows as $1/R_1$.

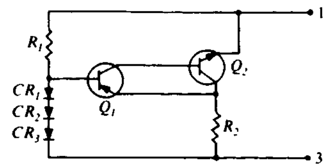
It is desirable that β be as large as possible, in order that R_1 may be as large as possible for a given choice of V_o. V_o is chosen as small as possible in order to minimize the power dissipation in the circuit.

Design Consideration: If desired, by adding a PNP transistor, Q_2, to the circuit as shown in sketch b, a high β variant of the circuit, in which the effective β is the product of the β's of transistor Q_1 and Q_2 can be obtained.

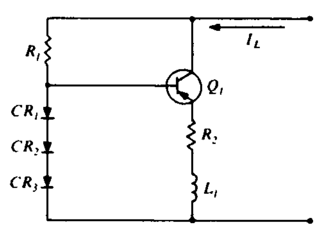
Another modification of the circuit is shown in sketch c. The inductor L_1 serves to control the rise time at the current I_L. Since L_1 is a two terminal device, it can be placed anywhere in the line. Another circuit variant is shown



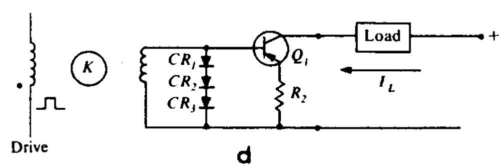
a



b



c



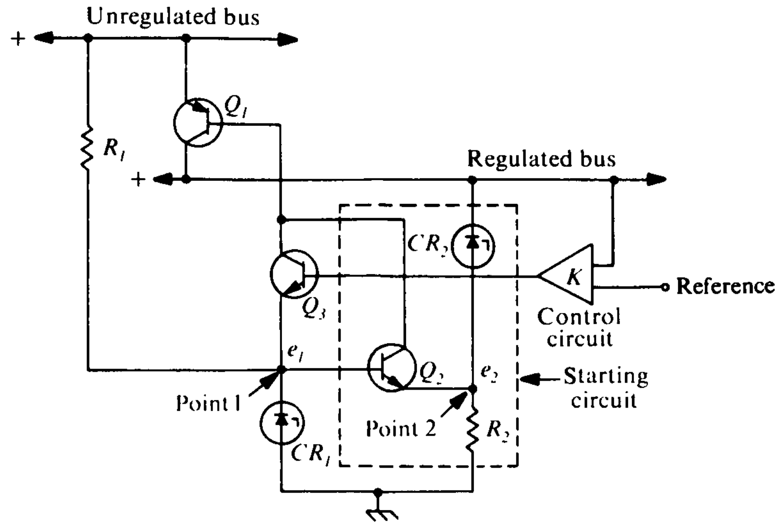
d

in sketch d. A square loop material magnetic core (K) is used as the driving source for Q_1. This circuit limits the pulsed current I_L through the load in nearly ideal fashion, since the diode current is not added to I_L; and at the same time it provides sharp timing because the diodes control the speed with which K switches. Rise time control may also be included as shown in sketch d.

Component values and parts list were not available at the time of publication.

Source: R. L. Alonso and
David Shansky
Massachusetts Institute of
Technology
under contract to
Manned Spacecraft Center
(MSC–27)

Regulated Power Supply Starting Circuit



APPLICATION: This circuit improves the loop gain of power supply regulator starting circuitry. The function of this starting circuit is basically to saturate the series transistor until the regulated output voltage reaches a given voltage determined by circuit design. When the output voltage is reached, the starting circuit is deactivated and the regulating circuitry controls the output to the desired value. This circuit may find general use in applications involving series-type voltage or current regulators, especially where high current and low voltage are required.

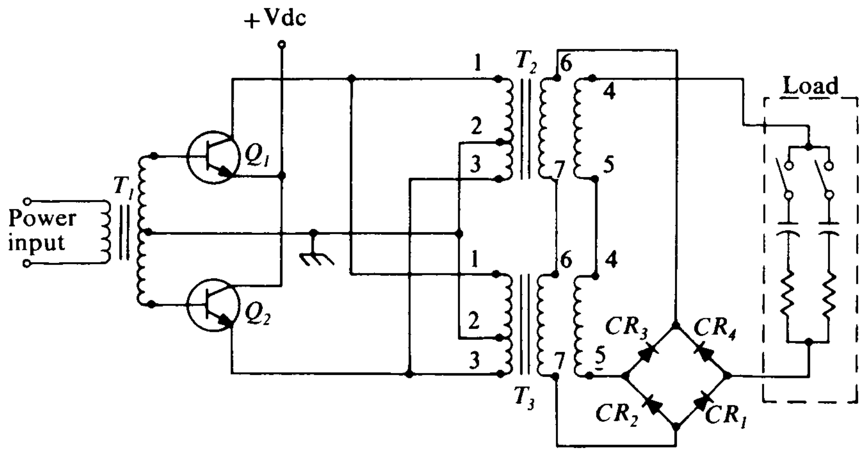
CIRCUIT DESCRIPTION: The starting circuit elements are transistor Q_2, zener diode CR_2, and resistor R_2. When the unregulated bus is energized, the voltage at point *1* is clamped at e_1 volts by zener diode CR_1. Until CR_2 breaks down, the voltage at point *2*, e_2, is e_1 minus the base-emitter voltage drop of Q_2. The emitter current of Q_2 is alpha (current gain) times the quotient e_2 divided by R_2. Since a path for Q_1 base current has been provided, Q_1 will conduct and the regulated bus voltage will start to rise. When the regulated bus voltage exceeds a voltage equal to e_2 plus the breakdown voltage of CR_2, the voltage at point *2* will rise. The emitter voltage of Q_2 will rise and become more positive than its base and Q_2 will cut off. As the regulated bus increases to its final value, Q_2 will remain cut off and normal regulator circuit operation will be established.

Component values and parts list were not available at the time of publication.

SOURCE: John F. Ringelman and
Henry B. Airth, Jr.
Westinghouse Electric Corporation
under contract to
Manned Spacecraft Center
(MSC–66)

Power Supply Tuning Technique for Capacitive Loads

APPLICATION: This circuit can find use in applications where it is desired to compensate for highly capacitive loads on a power supply. It may specifically be utilized to balance the variable capacitive load of computer logic controlled electroluminescent panel lights. The



circuit dissipates a minimum of power in its output stage and has good regulation characteristics. The circuit features simplicity and the use of low cost components.

CIRCUIT DESCRIPTION: The circuit is basically a transformer coupled class-B amplifier using a grounded collector power stage to keep the output impedance low and hence the regulation high. The two output transformers T_2 and T_3 are driven into magnetic saturation by the control windings (*6* to *7*) so that the inductive reactance, as seen from the emitters of Q_1 and Q_2, is equal to the capacitive reactance referred to the primary side of T_2 and T_3. Control windings (*6* to *7*) are driven by the load current through the full wave bridge made up of diodes CR_1, CR_2, CR_3, and CR_4. The inductive reactance therefore linearly tracks the capacitive reactance of the load. In all other respects, the circuit resembles a class-B push-pull power amplifier with 50 percent efficiency.

DESIGN CONSIDERATION: The output transformer circuits can be wound on a single stack of E-I laminations.

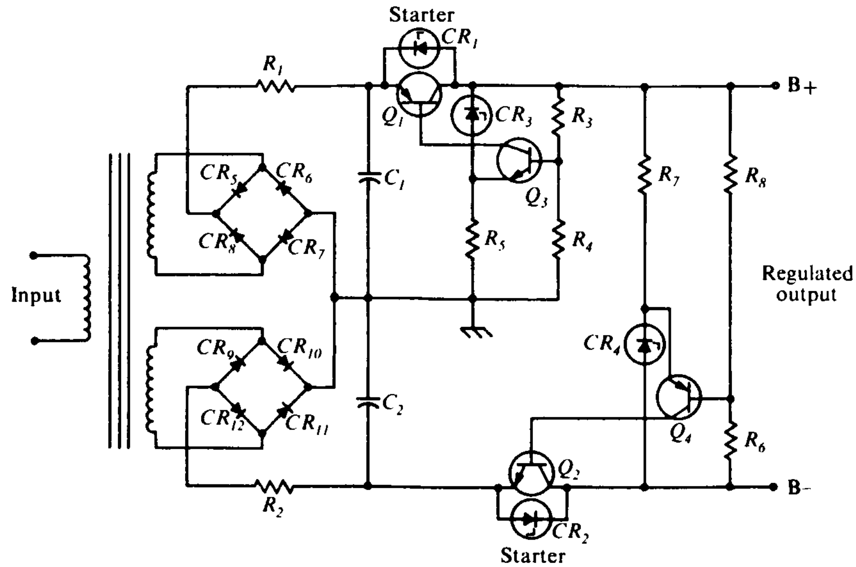
Component values and parts list were not available at the time of publication.

SOURCE: Manuel Kramer
Massachusetts Institute of Technology
under contract to
Manned Spacecraft Center
(MSC–70)

Zener Diode Starter for Transistor Regulated Power Supply

APPLICATION: This circuit uses a zener diode in parallel with a silicon transistor to supply the starting current for a power supply which features high quality silicon transistors as variable impedance regulators.

CIRCUIT DESCRIPTION: Zener diodes, CR_1 and CR_2, of suitable voltage rating are connected in parallel with the silicon transistors, Q_1 and Q_2, which are used as the variable impedance in each leg of the regulation portion



of the circuit. The voltages developed across the diodes provide initial current through the transistors, sufficient to turn them on. The silicon transistors, Q_1 and Q_2, require an initial starting current because they have exceedingly small leakage current.

DESIGN CONSIDERATION: The diodes are selected with zener voltage ratings large enough to provide sufficient starting current but small enough to be effectively open-circuited when the transistor is conducting.

Typical circuit elements and component values include:

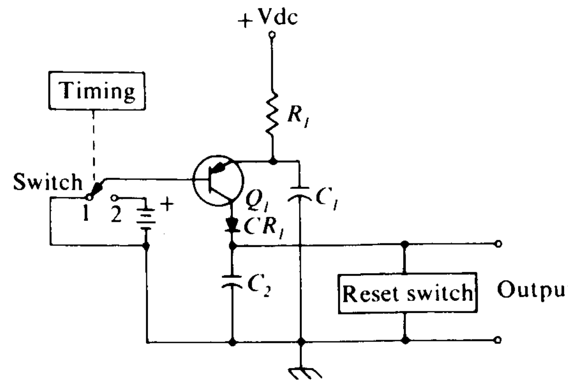
Supply	110 V 60 cps
Q_1, Q_4	2N1132
Q_2, Q_3	2N1893
CR_1	1N714
CR_2	1N712
CR_3	1N710
CR_4	1N468
CR_5 through CR_{12}	1N1218
R_1, R_2	3 Ω, 1 W
R_3	680 Ω
R_4	220 Ω
R_5	150 Ω
R_6	200 Ω
R_7	470 Ω
R_8	560 Ω
C_1	400 μF
C_2	200 μF

SOURCE: Westinghouse Electric Corporation under contract to NASA Space Nuclear Propulsion Office
(NU-0015)
B65-10052

Section 5

WAVE SHAPING CIRCUITS

Staircase Waveform Circuit



APPLICATION: This circuit can be utilized in programming applications such as physical or biological experiments for display of a family of characteristics simultaneously on a CRT. This circuit generates a staircase waveform of high-step uniformity, low-step droop and fast transition time using low input power and no feedback.

CIRCUIT DESCRIPTION: Capacitor C_1 is added to the emitter circuit of transistor Q_1 (a conventional gating stage). Resistor R_1 should be large enough to make C_1 the sole power source for transistor Q_1. Since the energy stored in C_1 is finite and discrete, the gate will remain open (conducting) during a timing pulse only as long as the emitter voltage remains greater than the base-emitter threshold. This *RC* circuit will, based on the low saturation resistance of Q_1, decay within the duration of any reasonable timing pulse.

The discharge of C_1 results in a pulse of collector current that imposes a discrete charge on the output capacitor C_2 and produces a corresponding step in the output voltage. The depletion of the charge on C_1 results in a quiescent cutoff condition in Q_1 that continues through termination of the timing pulse to the point in the following pulse at which C_1 is again discharged.

When the switch moves to position *2*, the rise in base voltage unclamps the emitter voltage which rises as C_1 charges through R_1 toward the supply voltage. Steady state is achieved well in advance of the next timing pulse and the amount of charge stored in C_1 will be known and discrete. Thus the discrete increments made in the output voltage are independent of the number of previous charging pulses and are unaffected by variations in timing frequency.

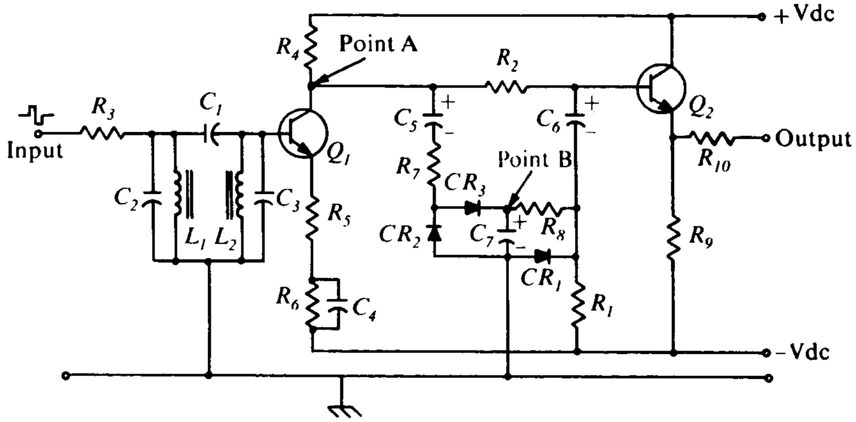
DESIGN CONSIDERATIONS: Equal step increments are achieved without feedback by transferring a charge from an input capacitor to an output capacitor in such a way that the transferred charge is independent of the state of charge of the output capacitor. Use is made of that property of a transistor whereby the collector current is proportional to the current flowing in the emitter circuit and independent, over a substantial range, of collector voltage.

Component values and parts list were not available at the time of publication.

SOURCE: George D. Breen
Goddard Space Flight Center
(GSFC–48)
B64–10007

Electronic Method of Sharpening Filter Slopes

APPLICATION: This circuit features the use of an electronic switch and discriminator as a frequency sensitive device. It is comparatively simple and can be utilized in various frequency discrimination and sorting applications where size, power consumption, and reliability are of prime importance. This circuit is especially applicable to modern telemetry



using FM/FM systems where subcarriers must not be allowed to interfere or approach each other too closely. The circuit could be used to eliminate interference arising from over-modulation (FM) of RF carriers.

Circuit Description: With the input to the circuit consisting of a square wave from a frequency modulated sub-carrier oscillator, the LC band pass filter in the input of the circuit removes harmonics of the square wave, thus reducing it to a sine wave. Transistor Q_1 acts as a voltage and filter buffer stage. Coupled to the Q_1 collector is a voltage-doubling rectifier, CR_2 and CR_3, and filter C_5; thus at point B appears a positive dc voltage that is proportional to the amplitude of the signal voltage at point A. While the input frequency is within the LC filter pass band, the voltage at point B is such that diode CR_1 is biased open, or in the non-conducting state. As frequency increases beyond the LC filter cutoff point, the voltage at point B drops due to LC filter action on the input signal, so that it is no longer sufficient to hold CR_1 open. At this time, CR_1 is biased into the conducting state by current from the minus voltage supply through resistor R_1. The resulting low impedance path from the base of transistor Q_2 to ground causes the signal voltage to be dropped almost entirely across the series resistor R_2. Transistor Q_2 is a buffer to provide a low impedance signal to an adding network.

Typical circuit elements and component values include:

Supplies	+ 6 V dc, − 6 V dc
Q_1	2N336
Q_2	2N333
CR_1	1N137A
CR_2	1N629
CR_3	1N629
R_1	360K
R_2	68K
R_3	82K
R_4	5.6K
R_5	820 Ω
R_6	9.1K
R_7	6.8K
R_8	39K
R_9	16K
C_1	.008 μF
C_2	.093 μF
C_3	.113μF
C_4	2.2 μF, 20 V dc
C_5	1 μF, 20 V dc
C_6	1 μF, 20 V dc
C_7	1 μF, 20 V dc
L_1	1 H
L_2	1 H

Source: Maxwell Strange and John Semyan
Washington Technological Associates for
Goddard Space Flight Center
(GSFC–53)

Complementary Regenerative Switch

APPLICATION: This circuit can deliver a square wave output from an undefined wave shape input, and can be manufactured in the form of a single chip molecular circuit for general incorporation into compatible electronic systems.

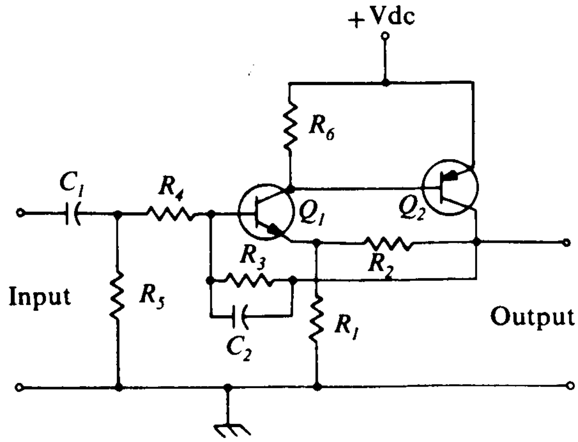
CIRCUIT DESCRIPTION: When the input voltage is applied, the circuit is regenerative, and when the input signal is removed the product of the forward gain and backward gain is less than unity and the circuit turns itself off. The circuit turns on when the input voltage is $E_{on} = \frac{V_{co}}{G}$; where V_{co} is that voltage that causes the transistor Q_1 to turn on if it were isolated from the circuit and G is equal to: $G = 1 - \frac{(R_2 + R_1)}{R_1 + R_2 + R_3 + R_4}$. The circuit turns off when the voltage is:

$$E_{off} = E_1 \left(\alpha + \alpha \frac{Y_3}{Y_4'} - \frac{Y_3}{Y_4'} \right) - V_{be} \left(1 + \frac{Y_3}{Y_4} \right),$$

$$\alpha = \frac{R_1}{R_1 + R_2};$$

$$E_1 = E_c - V_{ce\ sat};$$

$$Y_3 = \frac{1}{R_3};$$



$$Y_4' = \frac{1}{R_4} + \frac{1}{\beta R_{12}};$$

$$R_{12} = \frac{R_1 R_2}{R_1 + R_2}$$

C_2 improves the high frequency response of the circuit.

DESIGN CONSIDERATION: The circuit is easily designed, reliable and by virtue of its low power consumption, may last over extremely long periods of normal use.

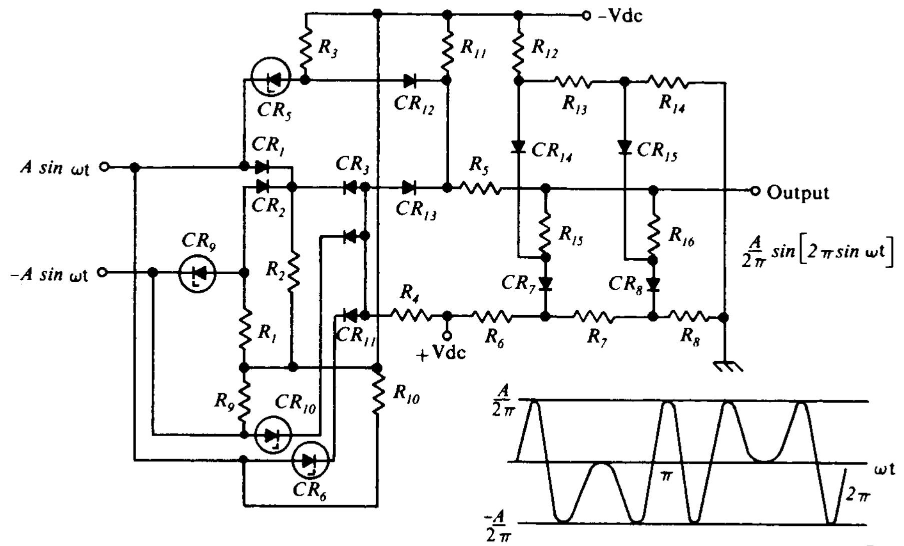
Component values and parts list were not available at the time of publication.

SOURCE: Leonard L. Kleinberg
Goddard Space Flight Center
(GSFC-207)

Variable Diode Function Generators

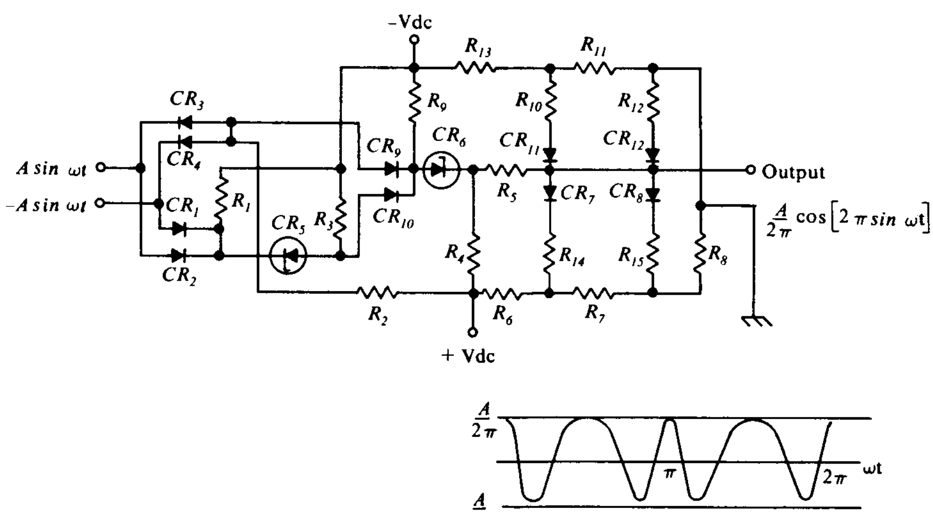
APPLICATION: These circuits generate the diode functions of sin $(2\pi \sin \omega t)$, sketch a and cos $(2\pi \sin \omega t)$, sketch b, at frequencies ranging from "high" to zero. The circuits can prove desirable for producing complex waveforms over a wide frequency range by combining sin and cosine functions. They feature simplicity and reliability by using diode function generation. A possible application is its use in the phased array control electronics for certain spacecraft.

CIRCUIT DESCRIPTION: The function waveform is produced by combining the outputs of four basic building block circuits which work functionally as greater takers (CR_1, CR_2, and R_1), lesser takers (CR_3, CR_4, and R_2), level shifters (CR_5, CR_6, R_3, and R_4), and diode shapers (CR_7, CR_8, R_5, R_6, R_7, and R_8). It is possible, by utilizing this method, to produce complex waveforms without mathematically reducing the desired function into a series, followed by summing the outputs produced by



Waveshape of function sin $[2\pi \sin \omega t]$

a



Waveshape of function cos $[2\pi \sin \omega t]$

b

circuits generating the forms represented by the individual series elements.

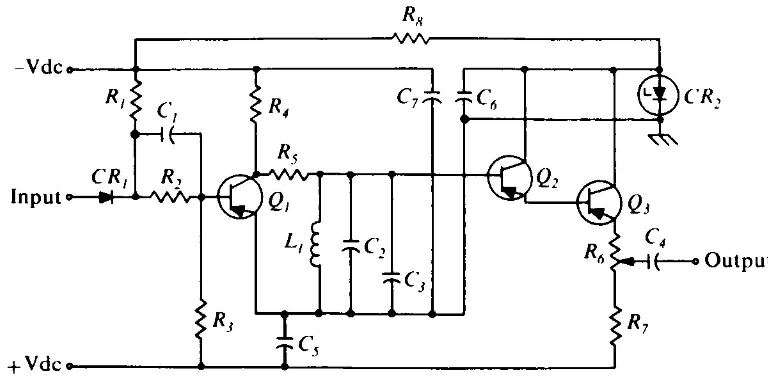
Design Considerations: Forward voltage drops of the greater and lesser taker diodes should be considered. If $A >> V_{df}$ the effect is negligible. However, in most cases $A > V_{df}$ and the drop is important. There are combinations of the building blocks in which the V_{df}'s of the diodes will compensate if in necessary places two diodes are used where functionally only one is required.

It is possible to eliminate some resistors, replace some of the diodes with emitter follower transistor configurations, or use greater or fewer components in the diode shaper for a particular circuit application.

Component values and parts list were not available at the time of publication.

Source: David Mead, A. Joseph McCall and J. David Callan
Hughes Aircraft Company
under contract to
Goddard Space Flight Center
(GSFC-214)

Frequency Filter Circuit



APPLICATION: This circuit provides a means of converting a rectangular input signal to a highly accurate and stable sine wave output.

CIRCUIT DESCRIPTION: Transistor Q_1 amplifies the input signal voltage to the filter consisting of resistor R_5 and the tuned tank circuit, inductor L_1, and capacitors C_2 and C_3. Tuning the tank circuit to the desired frequency is critical and is accomplished by careful selection of capacitor C_3. The output buffer stage of the circuit is a cascade emitter-follower amplifier consisting of transistors Q_2 and Q_3, connected in a Darlington emitter-follower configuration, isolating the tuned circuit and preventing it from being detuned or loaded.

DESIGN CONSIDERATION: The amplitude of the output signal is directly dependent upon the duty cycle of the input rectangular wave. For optimum operation the input signal should have a 50 percent duty cycle.

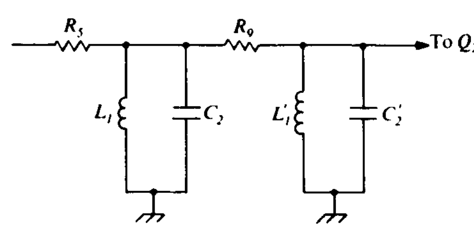
Several filter circuits covering different center frequencies may be constructed on individual circuit cards and packaged with corresponding impedance matching line drivers. This arrangement can be used as a portable system for providing coordinated timing signals to several locations.

Typical circuit elements and component values for the filters include:

Supplies	– 18 V dc
	+ 12 V dc
Q_1	2N1132
Q_2	2N1132
Q_3	2N1132
CR_1	1N695
Zener CR_2	–
R_6	1K
R_7	500 Ω
R_8	220 Ω
C_1	150 pF
C_4	0.47 μF, 50 V dc
C_5	0.068 μF
C_6	0.068 μF
C_7	0.068 μF

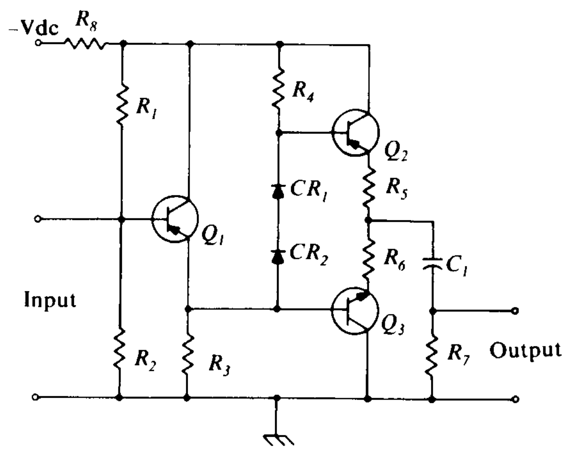
Comp.	1 Kc Filter	10 Kc Filter	100 Kc Filter
R_1	6.8K	6.8K	3.9K
R_2	2.2K	2.2K	8.2K
R_3	22K	22K	39K
R_4	1.2K	1.2K	3.9K
R_5	39K	39K	24K
R_9	10K	—	—
C_2	0.068 μF (2)*	0.033 μF	820 pF
L_1	0.25 H (2)*	8 mH	2.5 mH

*1 Kc Filter, Two Filter Stages.



SOURCE: Jack Thacker
Goddard Space Flight Center
(GSFC-232)

Impedance Matching Line Driver



APPLICATION: This circuit provides a means of impedance matching between a frequency filter circuit and a low impedance coaxial cable.

CIRCUIT DESCRIPTION: The input stage of this circuit is an emitter-follower consisting of transistor Q_1 and represents a high input impedance. The output stage is a complementary-symmetry emitter circuit consisting of transistors Q_2 and Q_3, which are capable of driving a low impedance coaxial cable (90 ohms) terminated in its characteristic impedance without noticeable distortion. Diodes CR_1 and CR_2 provide bias for transistors Q_2 and Q_3, maintaining a voltage difference between the bases of the transistors to eliminate crossover distortion. Transistor Q_3 conducts on the positive half of the input sine wave and transistor Q_2 conducts on the negative half.

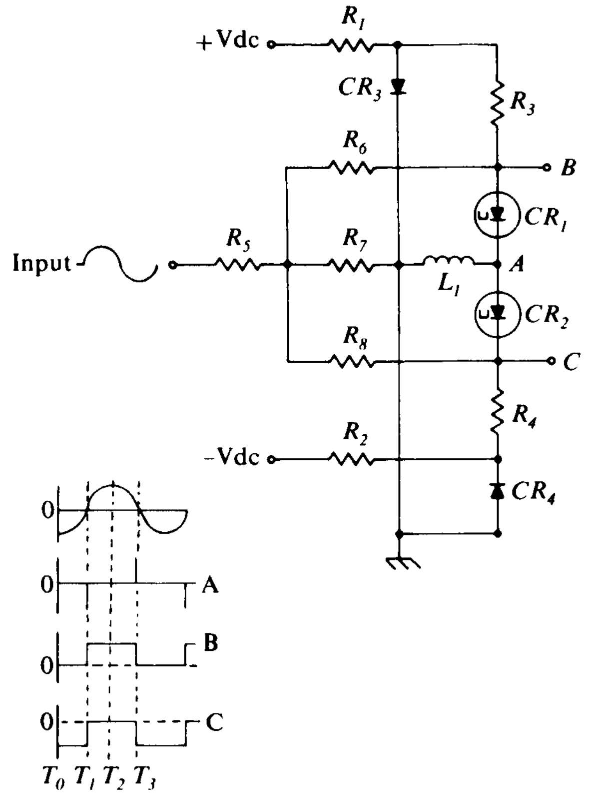
DESIGN CONSIDERATION: Several line drivers can be constructed on individual circuit cards and packaged with corresponding frequency filter circuits. The arrangement can be used as a portable system for providing coordinated timing signals to several locations.

Typical circuit elements and component values for the line drivers include:

Supply	– 18 V dc
Q_1	2N1132
Q_2	2N1132
Q_3	2N1132
CR_1	1N645
CR_2	1N645
R_1	11K
R_2	11K
R_3	1K
R_4	3.3K
R_5	10K
R_6	10K
R_7	10K
R_8	100 Ω
C_1	47 μF, 35 V dc

SOURCE: Paul McCaul and
Raymond Granata
Goddard Space Flight Center
(GSFC–232)

Tunnel Diode Clipping Circuit



APPLICATION: This tunnel-diode clipping circuit performs a clipping action as the input signal voltage crosses the zero axis. Separate terminals are included to provide both positive and negative clipping. This circuit can be used effectively as a limiter in FM receivers.

CIRCUIT DESCRIPTION: At time T_0, the input sine wave is at maximum negative value. Tunnel diode CR_1 is in the high current-low voltage mode, operating below the peak voltage point. Tunnel diode CR_2 is in the low current-high voltage mode. Minimum current is flowing in the R_2, R_4, CR_2 inductor circuit and a negative output appears at terminal C. Maximum current is flowing in the R_1, R_3, CR_1 inductor circuit and zero output appears at terminal B.

Between times T_0 and T_1, the input voltage becomes more positive, approaching the zero axis, the voltage across CR_1 approaches the peak voltage point and CR_1 current increases toward maximum.

As the input voltage crosses the zero axis at time T_1, the voltage applied to CR_1 reaches the peak voltage point and the diode switches, going to the low current-high voltage mode. Current in the R_1, R_3, CR_1 inductor circuit decreases rapidly. The rapid decrease of current in the inductor generates a large negative going pulse which, appearing at point A, switches diode CR_2 to the high current-low voltage mode. Output at terminal C rises to zero and output at terminal B rises to a positive maximum.

These output conditions prevail as the input signal reaches a positive maximum at time T_2 and decreases, approaching the zero axis. As the input voltage crosses the zero axis at time T_3, effects similar to those at time T_1 occur. Diode CR_2 switches to the low current-high voltage mode, the positive pulse generated by the inductor at point A switches CR_1 to the high current-low voltage mode, the positive output at terminal B drops to zero and the output at terminal C drops to a negative maximum.

Within the operating limits of the circuit, the positive and negative pulses appearing at terminals B and C respectively will rise and fall in exact coincidence with the input signal crossing the zero axis. Switching time is in the nanosecond range. This accuracy is achieved without regard to the frequency, amplitude or shape of the input signal. Resistors R_1 and R_2 and diodes CR_3 and CR_4 establish bias and compensation for the tunnel diodes. Resistors R_3 and R_4 are the load resistors for outputs B and C respectively.

DESIGN CONSIDERATIONS: Circuit components must be chosen to ensure that diodes CR_1 and CR_2 are both biased exactly at the peak voltage point. With no signal applied to the input, no current must flow through the inductor and terminals B and C must have equal and opposite polarities.

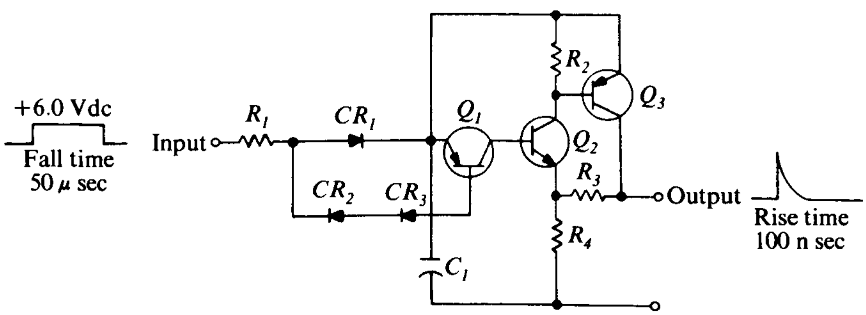
Typical circuit elements and component values include:

Supply	4 V dc
CR_1, CR_2	TN3712
CR_3, CR_4	HU5

L_1	100 μH
R_1, R_2, R_6, R_7, R_8	1K
R_3, R_4	680 Ω
R_5	5K

SOURCE: Edgar G. Bush
Goddard Space Flight Center
(GSFC-241)
B65-10002

Synchronized Pulse Generator Without External Power



APPLICATION: This circuit features generation of a fast rise time output pulse, synchronized with a rectangular input pulse of relatively slow rise and fall times, without the use of external power.

This circuit will generate a sharp output pulse with a rise time of 100 nanoseconds during the 50 microsecond fall time of + 6 V dc rectangular input signal as follows:

CIRCUIT DESCRIPTION: During the time the input signal is at + 6 V dc, charging current flows into capacitor C_1 through input resistor R_1 and diode CR_1. A large input impedance is obtained by making R_1 large. By proper choice of the capacitance value, the capacitor will charge to approximately + 6.0 volts in the time the input pulse remains at this voltage.

In this time interval, all transistors are biased off so that the capacitor retains its charge. When the input signal drops from + 6.0 volts to approximately + 4.0 volts, so that diodes CR_2 and CR_3 are forward biased, transistor Q_1 conducts and puts out a signal which turns on amplifier stages Q_2 and Q_3 to yield a sharply rising pulse. The effective supply voltage for the amplifier is obtained from the charge on the capacitor which discharges exponentially through transistors Q_2 and Q_3 to produce a corresponding exponential fall in the output pulse.

DESIGN CONSIDERATIONS: 1. An output may be obtained on the rise time of a negative going input pulse by use of NPN transistors for Q_1 and Q_3, PNP transistor for Q_2, and by reversing the polarity of diodes CR_1, CR_2, and CR_3.

2. The point during the fall or rise time of the input signal at which an output pulse is obtained is determined by the forward voltage drop across diodes CR_2 and CR_3. This point may be varied by changing the number of diodes used in the CR_1-CR_2 position, or it may be made very stable by replacing these diodes with a zener diode.

3. A tunnel diode may be incorporated into the circuit to obtain an output pulse rise time, independent of the input pulse rise-or-fall time.

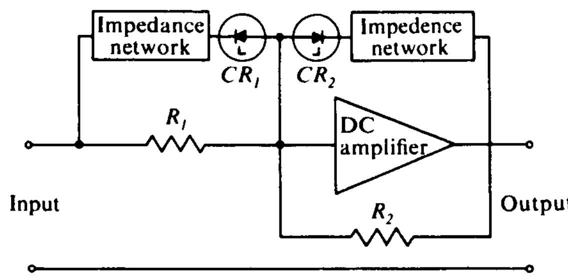
Typical circuit elements and component values include:

Q_1, Q_3	2N2894
Q_2	2N2369

CR_1, CR_2, CR_3	1N4153
R_1, R_4	100K
R_2	3K
R_3	10K
C_1	0.1 μF

SOURCE: Ciro A. Cancro and
Paul J. Janniche, Jr.
Goddard Space Flight Center
(GSFC-274)
B65-10072

Zener Diode Function Generator



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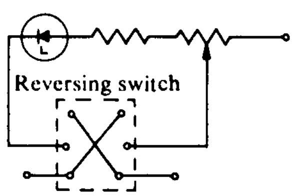


Basic impedance cell

b

APPLICATION: This is a function generator circuit using zener diodes to create reasonably stable functions with temperature variations and without an external reference voltage. The circuit provides a wide variety of breakpoints and can repeat operations with a minimum of recalibration.

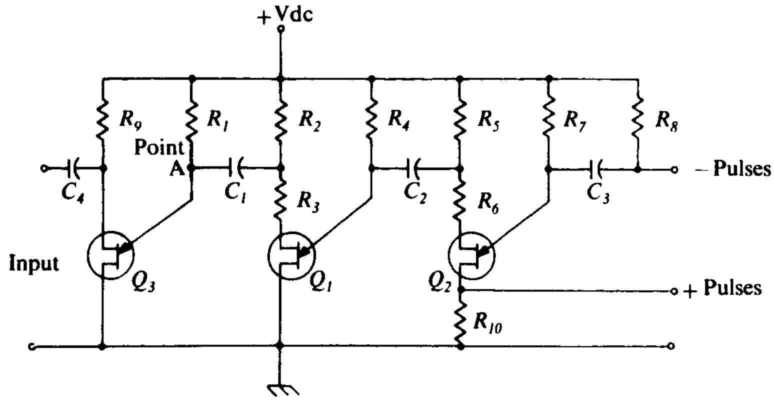
CIRCUIT DESCRIPTION: In sketch a, an input signal is fed into resistor R_1, connected in parallel with an impedance network and zener diode CR_1. In series with these circuit elements is another parallel network consisting of zener diode CR_2, a second impedance network, a high-gain dc amplifier, and resistor R_2. The function generated appears at the output of this parallel network as a voltage varying in time.

The nature of the function generated depends on the two impedance networks. The network may consist of one or more basic cells (parallel connected) such as that in sketch b. The basic cell has a reversing switch for effecting an interchange of the external connections, a zener diode, a resistor, and potentiometer, all connected in parallel. The diode is selected for its zener voltage which determines the point in the generated function at which there is an abrupt change in the slope. This voltage is the point where the resistance in the backward direction is very low.

Component values and parts list were not available at the time of publication.

SOURCE: George Bolte and Robert Burns
Jet Propulsion Laboratory
(JPL-0031)
B65-10013

Unijunction Frequency Divider



APPLICATION: This is a simple frequency divider using unijunction transistors and featuring few elements per stage, thereby reducing backward loading to a minimum. It can be applicable in timing devices and sync generators for television systems.

CIRCUIT DESCRIPTION: A relaxation oscillator makes up each stage of this frequency divider. Capacitor C_1 quickly charges through resistor R_2 and slowly discharges through resistors R_1 and R_2. The charging current through R_2 lowers the voltage at point A and may cause the next stage to conduct. However, a large value of R_3 will keep the current through the base of unijunction transistor Q_1 low so that the size of the pulse generated in R_2 is held sufficiently low that one stage will not trigger a preceding stage. Thus, the circuit reduces loading of each stage by feeding each output into a low impedance loop.

Backward loading is reduced since the synchronization signal of each stage is picked up by a high impedance loop in the following stage. This high impedance loop results in low currents which do not create appreciable sync voltage in the preceding stage.

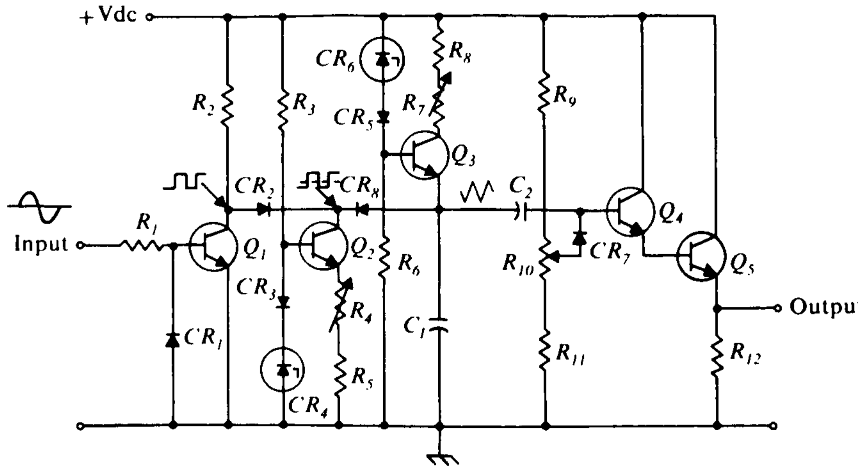
Component values and parts list were not available at the time of publication.

SOURCE: Avard F. Fairbanks
Jet Propulsion Laboratory
(JPL–W00–010)
B65–10112

Triangular Wave Generator

APPLICATION: This circuit can be utilized to generate a controlled triangular waveform using a sine wave drive. The circuit is simple and can find use in function generators, analog simulators, and no flyback scan CRT displays. The circuit may also be used in both analog-to-digital and dc to dc converters which employ pulse-width modulation in their control loops.

CIRCUIT DESCRIPTION: A sine wave is applied to resistor R_1. It is clipped by diode CR_1 and the diode action of the transistor, Q_1, base-emitter junction. This will result in a square wave at the collector of Q_1. Transistors Q_2 and Q_3 are constant-current sources with the current being established by the voltage across the emitter and collector resistances respectively. The voltages are held constant by the



zener diodes CR_4 and CR_6 while the variable resistors R_4 and R_7 are adjusted for the desired current.

During the up level of the square wave produced at the collector of Q_1, current is supplied through diode CR_2 to Q_2, thus causing diode CR_8 to be back biased. This allows the constant current from Q_3 to charge capacitor C_1. As the square wave drops to its down level, the collector voltage of Q_2 follows until it causes forward biasing of CR_8. Under this condition CR_2 is back biased and current is supplied to Q_2 from C_1 and Q_3. The emitter of Q_2 receives a current twice the value of the current required to charge C_1. Since Q_3 supplies half this current, C_1 must supply the other half and consequently discharges at the same rate as it was charged. The result is a triangular wave with linear slopes.

The dc component of the resulting waveform is removed by capacitor C_2. Direct current is restored to the signal with the resistance ratios R_9, R_{10}, and R_{11} through diode CR_7. A pair of Darlington transistors, Q_4 and Q_5, is used for isolation.

DESIGN CONSIDERATION: Transistors Q_4 and Q_5 should be impedance matched since the output impedance is much higher than that of the load.

Component values and parts list were not available at the time of publication.

SOURCE: R. G. Berns
International Business Machines
under contract to
Marshall Space Flight Center
(M–FS–165)

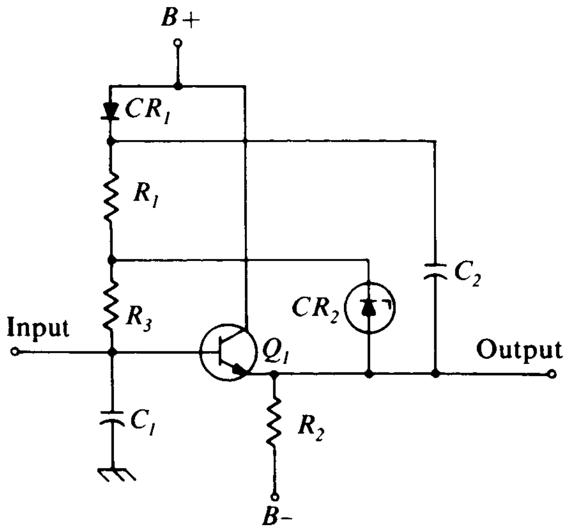
Improved Bootstrap Circuit

APPLICATION: This circuit can be used in applications where a linear sawtooth sweep voltage is required, such as television or oscilloscope sweep applications.

CIRCUIT DESCRIPTION: By the addition of a second bootstrap loop, this circuit combines the best features of previous bootstrap designs without any of their inherent limitations. By bootstrapping the voltage applied to resistor R_1, the zener current is maintained relatively constant during generation of the sweep, and the peak voltage is not limited by the B+ voltage. The capacitor C_2 used in the feedback loop is allowably smaller when used in conjunction with the zener diode CR_2. This permits a faster recharge time, resulting in less sensitivity to pulse repetition frequency variations. Also, due to the additional voltage supplied by the feedback capacitor, any change in the slope of the output sweep voltage due to the dynamic resistance of the zener diode will be minimized. The result is a circuit which is not sensitive to fluctuations in the pulse repetition frequency or supply voltage, and in which the amplitude of the output sweep voltage can exceed the B+ voltage. Also, the generated sweep voltage is more nearly linear than sweep voltages generated by previous methods.

Component values and parts list were not available at the time of publication.

SOURCE: Charles Headley, et al.
Westinghouse Electric Corporation
under subcontract to
Manned Spacecraft Center
(MSC-68)

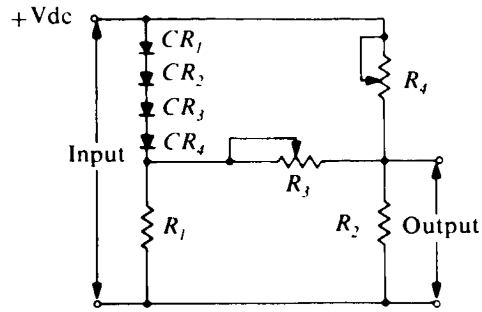


Section 6

TEMPERATURE COMPENSATION CIRCUITS

Simple Circuit for Linear Temperature Compensation

APPLICATION: This is a simple bridge circuit utilizing temperature compensating diodes and an adjustable voltage divider. An adjustable output voltage is provided which also varies linearly with temperature and can be used in various adjustable voltage applications.



CIRCUIT DESCRIPTION: This bridge circuit is formed with diodes, CR_1, CR_2, CR_3, and CR_4, in one leg. The voltage drop, across the diodes, decreases linearly with temperature over a limited range. Variable resistor, R_4, is adjusted for bridge balance at room temperature (25° C). Under balance conditions, variable resistor, R_3, has no effect on the output voltage. At all other temperatures, within a prescribed range, the bridge will be unbalanced due to the fact that the voltage drop across the diodes decreases linearly as the temperature increases above the balance condition or, conversely, the voltage drop increases linearly as the temperature decreases.

The voltage output is a linear function of temperature, provided that R_4 and resistor R_2 are of sufficiently high resistance to cause the current in the diodes to change negligibly over the operating temperature range. Under these conditions, R_3 serves as a voltage divider between R_2 and R_4. If the value of R_3 is changed from its initial setting, the output voltage will change correspondingly. This voltage can be varied from zero up to the full voltage drop across the diodes by adjusting R_3 to vary from infinity to zero.

DESIGN CONSIDERATION: Diodes were selected as the temperature variable device because of their small size and the fact that their forward voltage drop decreases linearly with temperature over the range of interest. This circuit should be satisfactory over the temperature range of $-20°$ to $+80°$ C.

Component values and parts list were not available at the time of publication.

SOURCE: Larry W. Moede
Datametrics Corporation
under contract to
Jet Propulsion Laboratory
(JPL–W00–029)
B63–10537

Zener Diode Drift Compensation

APPLICATION: This circuit can be utilized to obtain a precision internal reference voltage in a high-precision power supply. Standard cells cannot be used because of severe environmental conditions. A thermistor compensation technique is used for reducing the temperature drift of the zener diode, thereby maintaining the drift characteristics within the desired limitations. The techniques can be applied to electronic equipment requiring minimum-drift zener-regulated circuits.

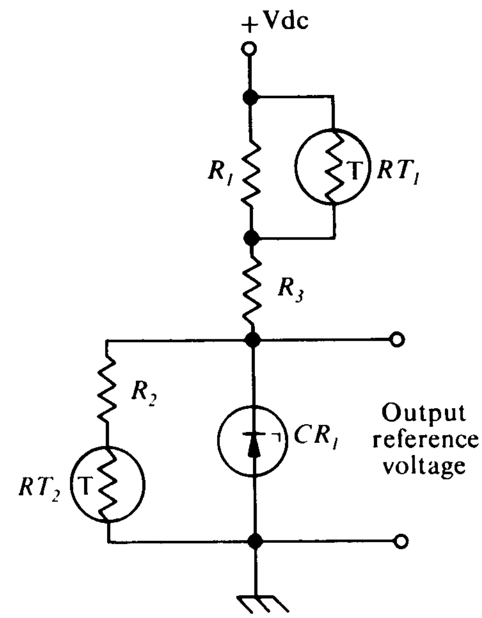
CIRCUIT DESCRIPTION: This method of temperature compensation can be used with zener diodes which exhibit an inverted parabola temperature drift characteristic. Resistor R_1 and thermistor RT_1 are connected in parallel to form a temperature compensation network. This network provides compensation for increasing temperatures by increasing the zener current which increases the zener voltage due to the dynamic impedance of zener diode CR_1. The R_1, RT_1 network exhibits a much larger effect for increasing temperatures because the thermistor's negative temperature coefficient causes a larger percent change in the parallel combination going hot than going cold. This is because any combination (series or parallel) of fixed and variable resistors can produce a non-linear effect.

Resistor R_2 and thermistor RT_2 are series connected to provide a second temperature compensating network. This network produces a similar effect for decreasing temperatures and has a small effect at high temperatures.

DESIGN CONSIDERATION: With proper selection of resistors R_1 and R_2, the network can be adjusted to closely compensate a normal zener temperature drift characteristic.

Component values for a typical circuit are as follows:

CR_1	1N940
RT_1	100 Ω
RT_2	10K
R_1	22 Ω
R_2	47K
R_3	715 Ω

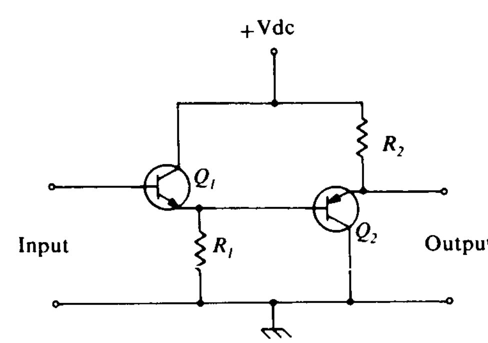


SOURCE: Dynatronics, Inc. under contract to Marshall Space Flight Center (M–FS–195)

Two-Stage Emitter-Follower Is Temperature Stabilized

APPLICATION: This technique can find applications where an emitter-follower circuit, with output voltage unaffected by environmental temperature changes, is needed.

CIRCUIT DESCRIPTION: This two-stage emitter-follower circuit uses one NPN transistor, Q_1, and one PNP transistor, Q_2. When Q_1 and Q_2 are connected as shown in the circuit diagram, an increase in temperature will cause the base-to-emitter voltage of Q_1 to become less positive. The base-to-emitter voltage of Q_2, consequently, will become less negative to a nearly equal degree, so that the temperature induced variations will tend to cancel. As a result, the output voltage of emitter-follower Q_2 will remain essentially unaffected by temperature within a prescribed range.



DESIGN CONSIDERATION: With typical transistors, such as 2N780 (Q_1) and 2N869 (Q_2), the output voltage average variation will be approximately 25 mV over a temperature range of $-20°$ to $+200°$ F. Transistor characteristics need not match, but overall compensation can be improved by complementary selection.

Typical circuit elements and component values include:

Q_1	2N780 or 2N910
Q_2	2N869
R_1	20K
R_2	20K

SOURCE: McDonnell Aircraft Corporation
under contract to
Manned Spacecraft Center
(MSC-20)
B63-10493

Section 7

CONTROL CIRCUITS

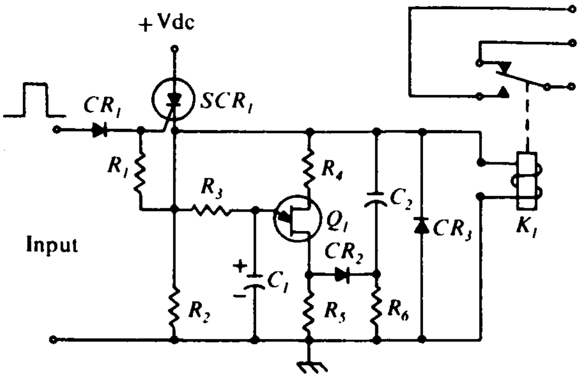
One-Shot Relay Driver

APPLICATION: This one-shot relay driver circuit is a simple, reliable device which will operate a relay for a period of approximately 50 seconds at a rate of once every minute. The circuit features an immunity to both positive and negative transients in the power supply and can find general use in control mechanisms.

CIRCUIT DESCRIPTION: A trigger pulse applied through diode CR_1 turns the silicon controlled rectifier SCR_1 ON. A voltage develops at the cathode of SCR_1 which closes the relay K_1 and provides biasing for the unijunction transistor Q_1.

Capacitor C_1 charges through resistor R_3 toward the peak emitter point of Q_1 turning it ON. This allows C_1 to be discharged across the emitter-base zone impedance of Q_1 and resistor R_5. The voltage across R_5 is coupled through diode CR_2 and capacitor C_2 to the cathode of SCR_1. The added voltage effectively back-biases the anode-cathode junction of SCR_1, reducing its current below its holding value and turns it OFF.

The starting pulse must be long enough for the relay current, flowing through SCR_1, to rise to a value equal or greater than the latching current of SCR_1. If the pulse is too short, a series resistor and capacitor may be placed in parallel with the relay coil to provide sufficient latching and holding current until the relay current has reached the required magnitude.



DESIGN CONSIDERATION: The illustrated circuit has been operated over a temperature range of –30° to 80° C.

Typical circuit elements and component values include:

Supply	+ 12 V dc
K_1	220 Ω
SCR_1	3J60
Q_1	2N1671B
CR_1, CR_2, CR_3	1N645
R_1	2.2K
R_2	4.7K
R_3, R_4, R_5	100 Ω
R_6	10K
C_1	100 μF
C_2	1 μF

SOURCE: Justin C. Schaffert and Norman E. Goldman
Goddard Space Flight Center
(GSFC–34A)

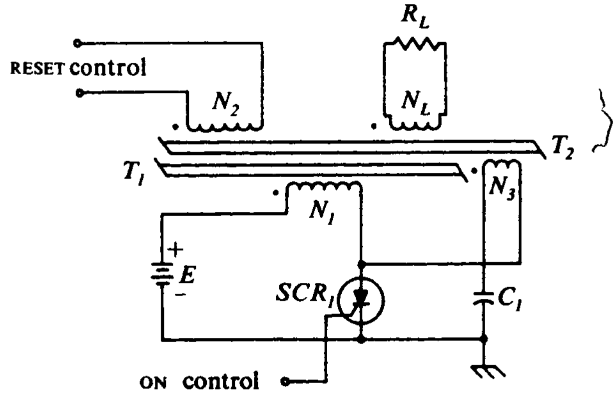
Unique Method for Turning Off Silicon Controlled Rectifiers

APPLICATION: This simple, reliable circuit uses passive elements for control of SCR's. It can find use in any SCR circuit application such as amplifiers, dc to ac parallel inverters and bilateral gating circuits.

CIRCUIT DESCRIPTION: A unique transformer is the basic element used in this turn-off circuit. The transformer is made up of two separate cores, T_1 and T_2. The primary winding N_1 is connected in series with the dc source. Primary winding N_1, load winding N_L, and reset winding N_2 encircle both cores, whereas the turn-off winding N_3 encircles only core T_2. The reset winding N_2 has no function during the interval that the silicon controlled rectifier, SCR_1, is conducting. The capacitor C_1 eliminates the dc path in parallel with the anode-cathode circuit of SCR_1, which would otherwise exist through winding N_3.

During the interval that SCR_1 is not conducting, the flux in core of T_1 is set toward the state of negative saturation by applying a voltage to the reset winding N_2 so as to make it negative. During this period the voltage across capacitor C_1 is at least equal to E and rises above this level during the resetting of the flux in core T_1. When SCR_1 is turned ON, C_1 discharges through winding N_3 and SCR_1 until the voltage on C_1 becomes equal to the approximate one volt drop across conducting SCR_1. When C_1 ceases to discharge, the current in winding N_3 will be zero. Core T_2 will then experience the same net magneto-motive force as core T_1. The magnetic characteristics of T_2 cause the flux level within this core to remain zero while core T_1 remains unsaturated. Turning SCR_1 ON causes the voltage E to be impressed across winding N_1. This causes the flux in T_1 to move, from negative toward positive saturation. SCR_1 continues to conduct until core T_1 becomes saturated in the positive direction, at which time core T_2 abruptly becomes effective. When core T_2 becomes effective, the voltage induced in winding N_3 will momentarily place a reverse charge across SCR_1, turning it OFF. As soon as C_1 charges to the voltage E, all currents in the circuit will become zero, and the flux core T_1 may be reset.

DESIGN CONSIDERATIONS: 1. The net rate of change of flux ($d\phi/dt$) in the two cores T_1 and T_2 will be fixed by the magnitude of the voltage E and the number of turns in winding N_1.



2. The maximum length of the conduction period is determined by the number of turns in winding N_1 and by the material and cross-sectional area of core T_1. It can be varied within this limit by controlling the resetting of the flux in core T_1 during the non-conducting interval.

3. In order to apply a reverse voltage to SCR_1 by winding N_3, the voltage of C_1 must be less than the voltage in winding N_3, and the turns ratio $N_1{:}N_3$ must be greater than unity.

4. Proper matching and selection of cores is required to assure correct operation.

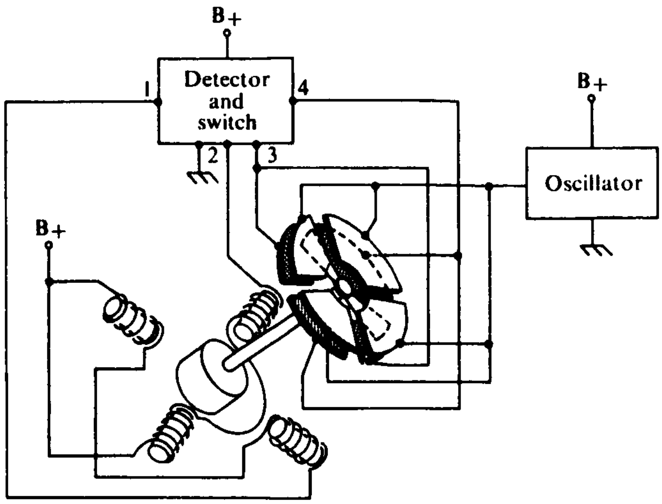
Component values and parts list were not available at the time of publication.

SOURCE: Thomas G. Wilson and Edward T. Moore
Duke University
under contract to
Goddard Space Flight Center
(GSFC–125)

Capacitive Switching for Brushless DC Motors

APPLICATION: This circuit is a method for driving the rotor of a brushless dc motor by switching the wound poles capacitively. This technique can be used wherever dc motors or ac synchronous motors are required to operate with minimum maintenance.

CIRCUIT DESCRIPTION: In this arrangement, as shown in sketch a, a set of stacked capacitor stator plates is provided for each wound pole of the motor. Commutation switching is then controlled by a capacitor rotor fixed to the motor shaft which passes between the



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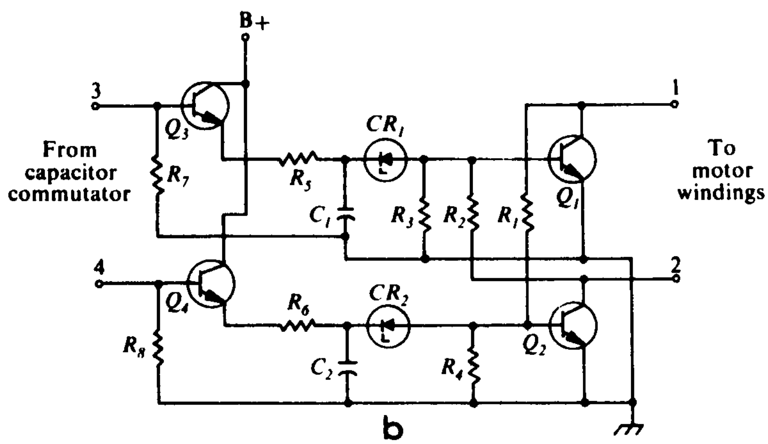


b

stacked stator plates. The capacitor rotor is designed to couple the two stator sections when the rotor plates are engaged. The capacitor rotor plate assembly is insulated from the motor shaft and requires no electrical contact to the shaft.

An ac carrier is supplied to one section of the stator plates. As the rotor plates rotate in and out of the stator plates, the coupling impedance is varied, resulting in a modulated carrier output from the second section of the capacitor stator plates. The modulated output is then detected and utilized to switch the appropriate wound poles of the permanent-magnet motor.

To control a detector and motor switching network, as shown in sketch b, a two part stator section would be required for each wound motor pole to be switched. Each stator section would have an ac signal applied to one part. When the rotor plates are in position to provide maximum ac flow from that section, the output from the second part would gate an electronic switch. The electronic switch being turned on would energize the motor pole associated with that capacitor stator section. This will cause the motor to advance which in turn will advance the capacitor rotor to the next capacitor stator section, thus switching the next motor pole.

DESIGN CONSIDERATION: It can be noted that the modulation amplitude does not vary with the rotational rate of the motors. Therefore, the capacitor system is compatible to motor starting, running and restart from stall.

This technique can also be applied to a 3-pole, Y-connected motor using three separate detector and switch networks between each motor winding and power supply, and using a suitably sectioned capacitive commutator.

Typical circuit elements and component values include:

Supply	100 V dc
Carrier	100 Kc sine wave
Q_1, Q_2	2N718
Q_3, Q_4	2N1304
CR_1, CR_2	1N750
R_1, R_2	4.7K
R_3, R_4	4.7K
R_5, R_6	470 Ω
R_7, R_8	100K
C_1, C_2	0.1 μF

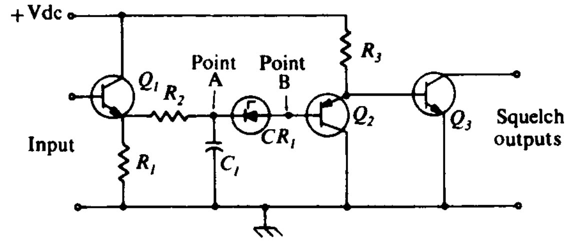
SOURCE: Pleasent T. Cole
Goddard Space Flight Center
(GSFC-176)

Circuit Recognizes and Rejects Noisy Signals in Pulse Systems

APPLICATION: This is a simple circuit for comparing signal and noise energies in pulse systems and to provide the basis for a decision to reject noise contaminated signals. The Circuit could be utilized in pulsed command and control applications and could also be used by amateur television and radio operators.

CIRCUIT DESCRIPTION: Resistor R_2 and capacitor C_1 form a simple integrating network, the integrating period being approximately the time required for one command word. This network is followed by a threshold device, zener diode CR_1 and two output stages to provide the squelch signal.

When the proper command is present in the decoder, the command signal being a series of pulse width modulated pulses, the integrated value of this signal at point A is insufficient to break down CR_1, and no signal appears at point B. However, when noise is present, the integrated value at point A is sufficient to break down CR_1 and a signal appears at point *B*. This signal turns transistor Q_2 OFF which in turn, causes transistor Q_3 to turn ON and provides a ground point as a squelch signal.



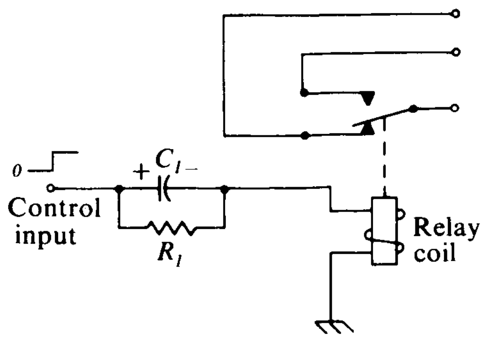
DESIGN CONSIDERATION: This circuit may require transistor leakage compensation and temperature stabilization.

Typical circuit elements and component values include:

Supply	+ 28 V dc
Q_1	2N718A
Q_2	2N722
Q_3	2N718A
CR_1	1N756A
R_1	39K
R_2	100K
R_3	150K
C_1	1.0 μF

SOURCE: J. Blair and J. Valachonic
Radio Corporation of America
under contract to
Goddard Space Flight Center
(GSFC-194)

Relay Power-Saving Circuit



APPLICATION: This simple circuit provides a means of conserving power during the hold-in time of large-hysteresis relays. The circuit can be utilized in dc relay control applications.

CIRCUIT DESCRIPTION: The hysteresis (ratio of pull-in current to hold-in current) of certain relays may be used to save power during relay hold-in time. This hysteresis is particularly large in the 1/6th crystal can size relays, in some cases as great as 3:1.

The time constant, $R_1 \times C_1$, allows the relay sufficient time to pull-in. The pull-in current flows through capacitor C_1 and resistor R_1; the hold-in current flows through R_1. The hold-in power is therefore only ⅓ of the pull-in power.

The capacitor provides the necessary extra power for the pull-in cycle. A power saving of 60 percent to 70 percent can be realized with this circuit.

DESIGN CONSIDERATION: Recovery time in high repetition operation may limit power saving ability to some extent.

Typical circuit elements and component values include:

Application to 500 ohm relay coil	
Control Input	+ 12 V dc Step
R_1	1K
C_1	22 μF

SOURCE: Justin C. Schaffert
Goddard Space Flight Center
(GSFC–205)

Motor Dynamic Brake Circuit

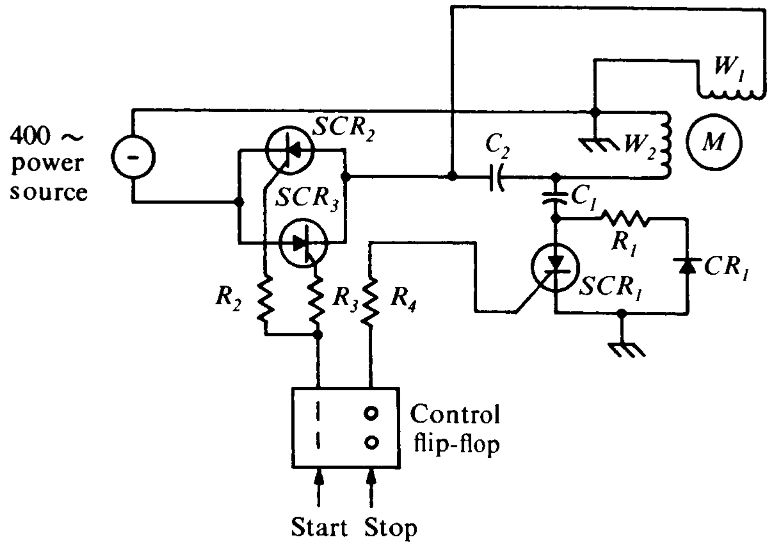
APPLICATION: This circuit provides an electronic braking system for hysteresis-synchronous motors used in control systems, servo systems, tape transport and stepper motor applications. It features low cost components, simplicity, and reliability.

CIRCUIT: In this circuit, a 400 cycle two-phase hysteresis-synchronous motor is used as an input and a conventional solid-state switch is used to control its operation. This switch consists of silicon-controlled rectifiers SCR_2, SCR_3, current limiting resistors R_2 and R_3 and the control flip-flop. When this flip-flop is in the one state, SCR_2 and SCR_3 are gated ON and 400 cycle power is applied to the motor windings. Capacitor C_2 provides the required phase shift to enable the two-phase motor to operate efficiently from the single-phase source.

During the time that the motor is operating, the brake switch SCR_1 is gated OFF and the brake capacitor C_1 charges through the path R_1, CR_1. When the control flip-flop is placed in the zero state (by a stop trigger) SCR_1 is gated ON by current flowing through R_4. The charge stored in C_1 is then allowed to surge through SCR_1 and the motor winding W_2. This provides a very powerful braking impulse to the spinning motor armature.

The value of C_1 is determined such that the time constant $C_1 \times$ resistance of W_2 is somewhat longer than the stopping time of the motor. For small motors this is in the order of tenths of a second. The time constant $C_1 \times R_1$ is set so that C_1 is fully charged in the minimum expected motor running time.

DESIGN CONSIDERATIONS: The parts essential to the brakes are C_1, R_1, CR_1, and SCR_1.



The other components are included for clarity and are not essential to this circuit. The switches SCR_2 and SCR_3 could be replaced by a relay without affecting the brake system.

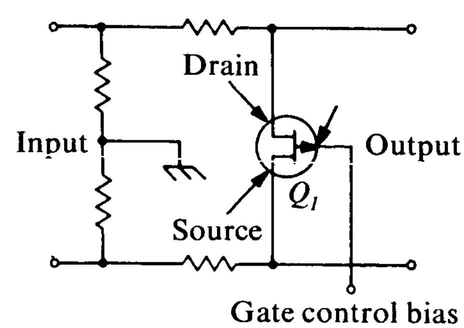
More effective braking can be accomplished, if necessary, by using a similar brake circuit in the other motor winding. This variation, however, may require the use of an isolation transformer to protect the switch and the 400 cycle source from brake current surges.

Component values and parts list were not available at the time of publication.

SOURCE: Arthur Vuozzo and
Thomas Callahan
Sylvania Electric Products, Inc.
under contract to
Goddard Space Flight Center
(GSFC–212)

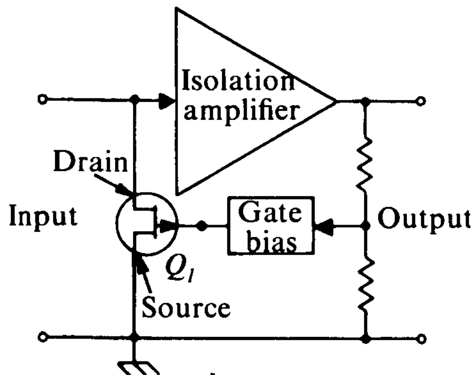
Field Effect Transistors Used as Voltage-Controlled Resistors

APPLICATION: These circuits can prove desirable for solid state applications in lieu of remotely controlled potentiometers. They feature reliability, simplicity and use of low cost components. The circuits can also be used in audio and video AGC stages, as bias drift monitors in precision input/output equipment, and in remote control circuits.



a

CIRCUIT DESCRIPTION: In sketch a, the FET Q_1 is operated in a balanced circuit with the control voltage applied to the drain connection and the inverse of the control voltage applied to the source connection. This results in a condition, at the midpoint of the FET Q_1 in the region of the gate, of virtual ground potential. The result is linear response of the FET over a wide range of control-voltage levels.



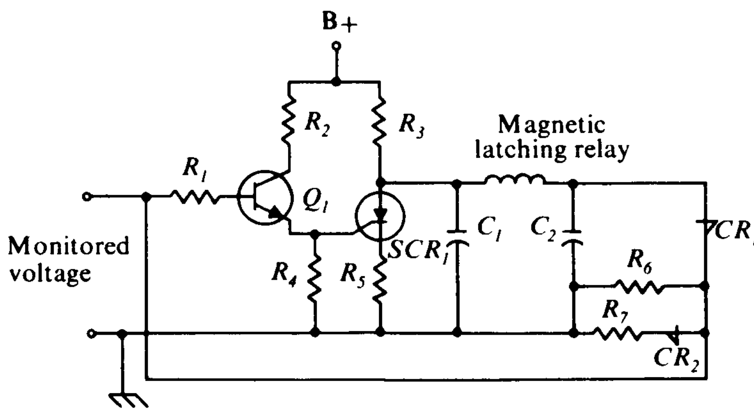
b

In sketch b, an alternate circuit, one-half of the control voltage appearing at the drain connection is capacitively coupled to the gate, thus cancelling the bias change that would otherwise result from a change of internal current resistance drop. This method results in linear response of the FET Q_1 over a wider range of control-voltage levels than does the previously outlined method. The isolation amplifier may be removed from the circuit but maximum circuit resistance will then be limited by the sum of the resistors in the divider network.

Component values and parts list were not available at the time of publication.

SOURCE: W. Y. Elliott, Jr.
International Business Machines
under contract to
Marshall Space Flight Center
(M–FS–174)
B64–10163

Polarity Sensitive Circuit



APPLICATION: This polarity sensitive circuit can prove useful for activating magnetic relays with changing polarity of low-level signals and features the use of a single power supply and few circuit components. The circuit should be useful for driving components which are sensitive to current directions and which require greater power than is normally available at the output of a high-impedance source.

CIRCUIT DESCRIPTION: The B+ power supply places approximately equal charges on storage capacitors C_1 and C_2. When the monitored voltage is positive, the silicon-controlled rectifier SCR_1 is triggered, and C_1 is quickly discharged. As a result, C_2 discharges through the relay, with a current flow from right to left. If the monitored voltage goes from positive to negative, SCR_1 becomes nonconductive and acts as an open switch, since an appropriate trigger voltage is not applied by transistor Q_1. The four-layer negative-resistance diodes CR_1 and CR_2 are then triggered to conduction, and C_2 is quickly discharged. As a result, C_1 discharges through the relay, with a current flow from left to right.

If the monitored voltage remains negative, CR_1 and CR_2 will continue to be conductive and the capacitors will remain discharged. If the monitored voltage subsequently goes from negative to positive, CR_1 and CR_2 become nonconductive, since they offer very high impedance in the reverse direction. Should the monitored voltage then remain positive, SCR_1 would remain conductive, and the capacitors would remain essentially discharged.

DESIGN CONSIDERATION: The circuit can be made quite sensitive by proper selection of components and introduction of gain stages at the input. The circuit is limited to applications of single coil magnetic latching relays.

Component values and parts list were not available at the time of publication.

SOURCE: Lawrence S. Smith
Electro-Optical Systems, Inc.
under contract to
Western Operations Office
(WOO-055)
B63-10508

Section 8

SPECIALIZED COMPUTER CIRCUITS

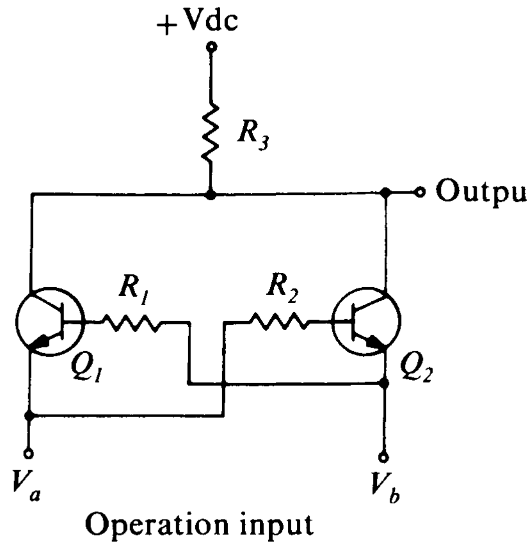
Exclusive OR Logic Circuit

APPLICATION: This is a simplified exclusive OR (half adder) logic circuit. It performs logic function manipulations easily and with minimal complexity. The circuit can be utilized in simplified binary computing and control operations and features the use of low cost components.

CIRCUIT DESCRIPTION: The circuit comprises two transistors, Q_1 and Q_2, and three resistors, R_1, R_2, and R_3. The mode of operation is such that when the voltages V_a and V_b are equal, the output voltage is equal to + V dc. When V_a and V_b are not equal, the output voltage is equal to the lesser of V_a and V_b.

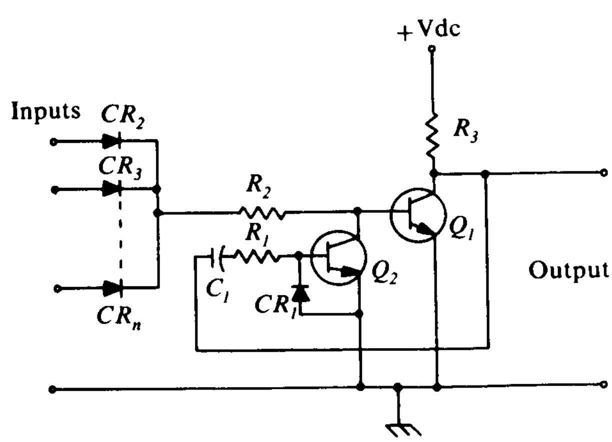
DESIGN CONSIDERATION: Transistors Q_1 and Q_2 should be selected for their matching characteristics. The voltage variations seen by this circuit in its application will have little, if any, effect on its operation.

Component values and parts list were not available at the time of publication.



SOURCE: Jerome A. Camp
Goddard Space Flight Center
(GSFC-144)

Circuit Combines Pulse Stretcher with NOR Gate



APPLICATION: This is a pulse-stretching circuit combined with a conventional NOR gate to provide an output pulse of some predetermined minimum duration. It may find application in square-root computers and with digital oscillators.

CIRCUIT DESCRIPTION: This is a pulse-stretcher circuit added to a conventional NOR gate circuit. With all inputs at ground potential, the output is positive, current flows through capacitor C_1 and resistor R_1 into the base of transistor Q_2, turning it ON. Current flows into the base of Q_2 until C_1 is charged, approximately three times the $R_1 \times C_1$ constant. If the inputs become positive while Q_2 is still conducting, transistor Q_1 will not be affected since its base is being held at ground potential by Q_2. The inputs regain control of the output when Q_2 stops conducting. A diode, CR_1, in series with R_1, provides C_1 with a discharge path to ground.

DESIGN CONSIDERATION: The circuit works equally well with PNP transistors, all polarities being reversed.

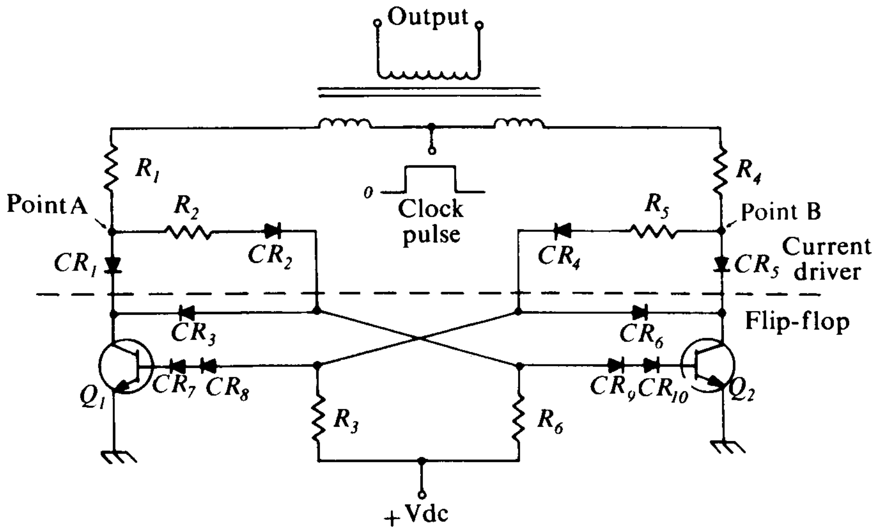
Typical circuit elements and component values include:

Transistors	2N708
Diodes	1N252
R_1	100K
R_2	10K
R_3	500K
C_1	0.001 μF

(Minimum duration $\approx$ 1 ms)

SOURCE: Rodger A. Cliff
Goddard Space Flight Center
(GSFC-187)
B64-10150

Logic Current Driver



APPLICATION: This circuit can be used in computer memory driving, and control applications. It features amplified bi-polar driving current directly from logic elements.

CIRCUIT DESCRIPTION: Operating with a standard low current flip-flop circuit, the current driver logically determines the state of the flip-flop, amplifies the current to the appropriate level and supplies the information current to a memory as follows: When the clock pulse input is at ground, the diodes between the current driver and the flip-flop are back biased, the flip-flop operates at its normal low current level, and there is no current flowing in the current driver network. The operation of the current driver is described, assuming transistor Q_1 is conducting and Q_2 is non-conducting. When the clock pulse is applied a slight voltage will appear at point A, and a voltage of about 80 percent of the clock pulse voltage at point B, and Q_1 will then saturate. The additional base current needed to meet this condition is supplied from point B through resistor R_2. Q_2 remains non-conducting because the voltage at point A is insufficient to pass any base current to Q_2. The current is transformer-coupled to the load, and if Q_2 were conducting instead of Q_1, current of opposite polarity would be coupled to the load. Essentially, the clock pulse serves the dual purpose of supplying the load current and of stepping the level of the flip-flop.

Typical circuit elements and component values include:

Supply	+ 5 V dc
Transformer	Core material: Indiana General T1 Core size: CF101
Q_1, Q_2	2N501
CR_1 through CR_6	1N3207
CR_7 through CR_{10}	MC45
R_1, R_4	412 Ω
R_2, R_5	1.87K
R_3, R_6	26.7K

SOURCE: C. F. Chong and C. A. Nelson
Remington Rand Univac
under contract to
Goddard Space Flight Center
(GSFC-213)

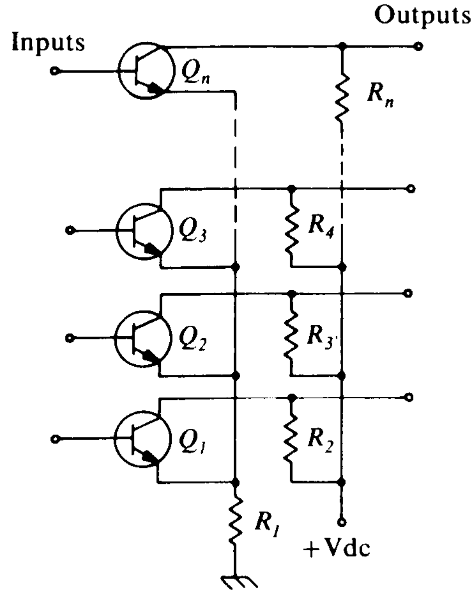
Transistor Voltage Comparator Circuit

APPLICATION: This transistorized voltage comparator can be directly coupled to a binary encoder for readout and for detection of the highest voltage input among a group of varying voltage inputs. The circuit uses individual transistors for both voltage sensing and logic functions and could be used to advantage wherever diode comparator gates are now in use.

CIRCUIT DESCRIPTION: One transistor is used for each input line being monitored. The base-emitter junctions of the transistors are connected as in a standard diode comparator circuit. The collector circuits of the transistors perform the sensing function.

The emitters of all the transistors are tied to one common resistor, R_1. Each transistor has a load resistor in its collector circuit. Applying a maximum input voltage on the base of transistor Q_1, the base-emitter junction of Q_1 will be the only one forward biased. Q_1 will be conducting and the voltage at the emitters of all transistors will be equal to the voltage on the base of Q_1 minus the voltage drop across the base-emitter junction of Q_1. Voltages on the emitters of all transistors, except Q_1, will be more positive than the voltages on their respective bases and they will be cut off. The output voltages of these transistors will be very high compared to that of Q_1.

DESIGN CONSIDERATIONS: Although NPN transistors are shown, PNP may be used



with reversed polarities. The input voltage levels will be governed by the transistors used.

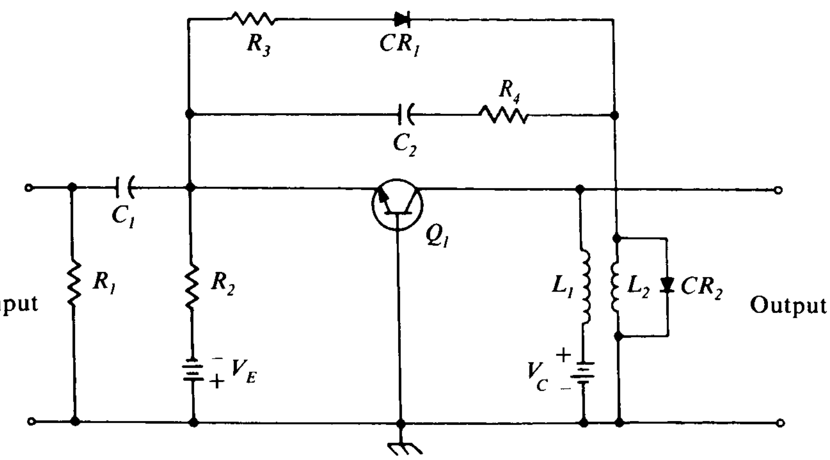
The individual values of resistors R_2, R_3, R_4, and R_N are much greater than R_1.

Typical circuit elements and component values include:

Supply	+ 20 V dc
Inputs	0 to 10 V dc
Outputs	20 or 10 V dc
$Q_1, Q_2, Q_3 \ldots Q_N$	2N780
R_1	100 Ω
$R_2, R_3, R_4, \ldots R_N$	100K

SOURCE: Rodger A. Cliff
Goddard Space Flight Center
(GSFC-228)
B65-10028

Feedback Oscillator Used as a Low-Level Pulse Stretcher



APPLICATION: This circuit can find application in the design of electronic pulse equipment, particularly for use in very low power digital computers.

CIRCUIT DESCRIPTION: This pulse stretch circuit is similar to a standard blocking oscillator. However, the high sensitivity (low trigger level) is obtained by forward biasing the emitter-base junction of the transistor Q_1. With proper selection of R_2 and V_E the collector bias current can be set to approximately 10 microamperes, thus keeping the loop gain below unity and preventing free-running oscillation.

When a negative input pulse is applied to the emitter of Q_1 through C_1, the current in the collector increases. As a result of this increase, a positive feedback voltage is coupled across coils L_1 and L_2, and through capacitor C_2 to the emitter of the transistor Q_1. This positive feedback continues until the voltage across L_2 is sufficient to turn on diode CR_1. The use of the secondary feedback path CR_1–R_3 permits pulse widths exceeding the charge time of capacitor C_2.

The secondary feedback path allows the use of a small value capacitor for C_2 to increase the recovery time of the circuit. The inclusion of swamping diode CR_2 across coil L_2 also results in a faster recovery time.

DESIGN CONSIDERATION: Typical trigger requirements for this circuit are a signal 30 nanoseconds wide at a level of 200 microamperes and 70 millivolts. Output pulses of 0.5 microsecond duration can be expected.

Component values and parts list were not available at the time of publication.

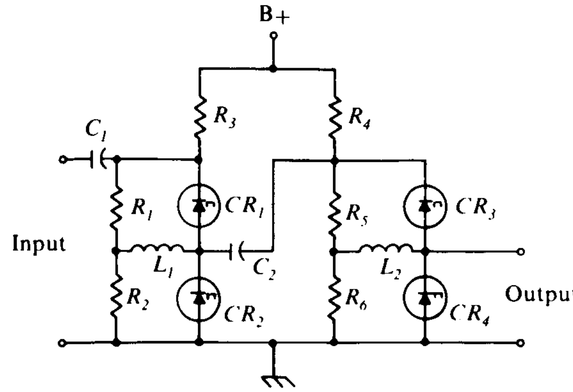
SOURCE: Sperry Rand Corporation
under contract to
Goddard Space Flight Center
(GSFC-261)
B65-10069

Tunnel Diode Binary Coupling Circuit

APPLICATION: This circuit, using tunnel diodes as bistable devices instead of transistors, can be used in digital computing or counting devices for applications such as vending machine counting or change making. The circuit features higher counting rates, redundancy, and low-power consumption. This type of coupling circuit will operate reliably with a variation of as much as ± 20 percent in the supply voltage.

CIRCUIT DESCRIPTION: The supply voltage, $B+$, and resistors R_1, R_2, and R_3, are selected so that when a pulse signal is applied to capacitor C_1, only one of the tunnel diodes CR_1 or CR_2 can be in the high-voltage state under steady-state conditions. The bistable operation of this circuit can be explained by assuming CR_2 to be initially in the low-voltage state; under this condition, the steady-state current flow is through inductor L_1 and CR_2. At this time, the small amount of current that flows through CR_1 is negligible. As C_1 discharges, the steady-state current is interrupted and the circuit currents are altered. The two diodes have a net voltage of zero across the pair because of the short circuit caused by C_1 discharging. To meet this condition and that imposed by the electrical inertia of the inductor L_1, current will continue to flow in the same direction through CR_2 and a reverse current will flow through CR_1. If C_1 starts to recharge while the shorted inductor current is still flowing, the current from $B+$ will algebraically add to the currents from the inductor, causing the operating points of both diodes to shift to a positive direction. When the current through CR_2 reaches its peak, CR_2 will switch to the high-voltage state and CR_1 will then go to the low-voltage state, thus the operation of the diodes have reversed conditions after one half cycle.

DESIGN CONSIDERATIONS: Capacitor C_1 must be selected so the discharge time is less than the L/R time constant of the circuit. If this condition is not met and the inductor current decays below a critical level, the steady-state condition will be unpredictable.



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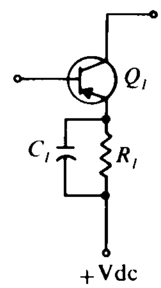


b

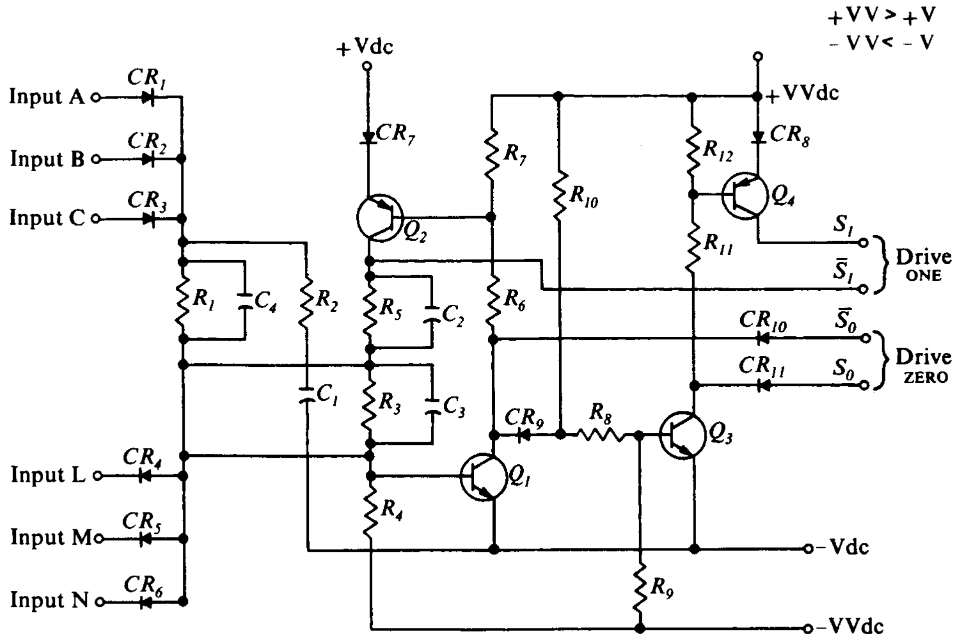
This circuit will function well through three stages but with a fourth stage will become erratic. This can be overcome by applying transistor rather than capacitive coupling between successive stages, as shown in sketch b, with the input applied to the base output taken from the collector, and using negative bias.

Component values and parts list were not available at the time of publication.

SOURCE: Edgar G. Bush
Goddard Space Flight Center
(GSFC–AE–10)

Logic Building-Block Circuit

APPLICATION: This circuit relates to a method of implementing logic equation $(A + B + C) \cdot L \cdot M \cdot N = S$ with passive components. The logic circuit is connected to four transistors which are interconnected in such a way that four low impedance outputs are provided, $\overline{S}_1$, $\overline{S}_0$, S_1, S_0. The output impedance is essentially the saturation resistance of a



transistor. The $\overline{S}_1$ or S_1 output is a *driven one* output, that is, the output has a low impedance to the power source defined as the *logical one* voltage. The $\overline{S}_0$ or S_0 output is a *driven zero* output, that is, the output has a low impedance to the power source defined as the *logical zero* voltage. Thus, the circuit is capable of driving circuits which require either a driven one or a driven zero. The circuit is comparatively simple and may find use in commercial logic circuitry.

CIRCUIT DESCRIPTION: A unique feature of the building block is a bistable circuit in which transistors Q_1 and Q_2 are simultaneously in the same state, either ON or OFF. With both Q_1 and Q_2 not conducting, Q_1 is biased off by R_4 which connects the base of Q_1 to a lower potential than its emitter. Q_2 is biased off by resistor R_7 which connects the base of Q_2 to a higher potential than its emitter.

When a large positive pulse is applied to the base of Q_1, it conducts and applies a negative pulse to the base of Q_2. Q_2 conducts and applies a positive going pulse to the base of Q_1. Thus, both transistors are forced into a stable conducting state. In a similar manner, both transistors are returned to the non-conducting state by a negative pulse. During the conducting state, the collector of Q_2 is connected to the +V power bus through the saturation resistance of the transistor and the collector of Q_1 is connected to the $-$V power bus through the saturation resistance of the transistor. Because of the cross-coupling between the transistors, a state in which one transistor is conducting and the other is non-conducting is unstable. Thus, this circuit accepts pulses to produce a steady-state output.

Transistors Q_3 and Q_4 are added so that a low impedance connection is available to the +V and $-$V busses when Q_1 and Q_2 are not conducting, and a diode logic network has been connected to the base of Q_1. The logic network implements the logic equation $(A + B + C) \cdot L \cdot M \cdot N + S = S_1 = S_0$.

DESIGN CONSIDERATION: If R_5 and C_2 are removed, the circuit produces the required output only while the proper signal is available at the base of Q_1. More elaborate logic equations can be implemented by an additional diode logic level.

Component values and parts list were not available at the time of publication.

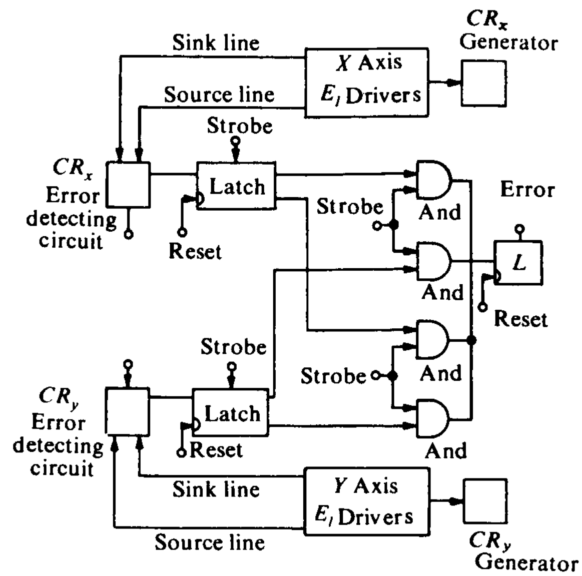
SOURCE: William Mosely Fitch
General Electric Company
under contract to
NASA Headquarters (HQ-16)

Address Current Error Detector

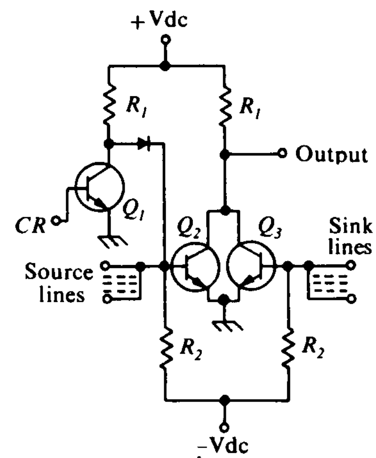
APPLICATION: This is a circuit for an address current error detector that generates a signal whenever an error-producing condition arises such as address without voltage source, without current sink, or without voltage source-current sink; address with multiple sources and single sink, with single source and multiple sinks, or with multiple sources and sinks, or transient addressing. The circuit is compatible with most memory configurations using source-sink addressing or driver-gate addressing or to determine signal coincidence in test equipment.

CIRCUIT DESCRIPTION: In the block diagram, sketch a, an error detecting circuit is provided for each addressing coordinate. The outputs of all the voltage sources and current sinks, and the coordinate address clock (*CR*, i.e., CR_x or CR_y) pulse are monitored by the associated error detecting circuit. If one source and one sink circuit are actuated when the current address clock pulse is present, no signal is generated by the error detecting circuit. However, if any other combination of sources, sinks, and the coordinate address clock pulse (present or absent) is impressed upon the error detecting circuit, it generates a signal that is processed by latch circuits and AND gates to present an error pulse at the output of the error detection system.

The error detecting circuit is shown in sketch b. In the absence of a *CR* pulse and any source of sink signal, transistor Q_2 is saturated. As a result, the bias current through R_1 and the output level are down. When only a *CR* pulse is present, Q_2 turns OFF and the output level is up. In this case, a single source signal or a single sink signal will not override the back bias through resistor R_2, and the output remains up. If two or more source signals are present, Q_2 turns ON and the output level is down. If two or more sink signals are present, transistor Q_3 turns ON, and the output level is down. The *CR* pulse is not generated unless one source signal and one sink signal are present. Thus, during the time of a strobe signal at the AND gates, an up level



a



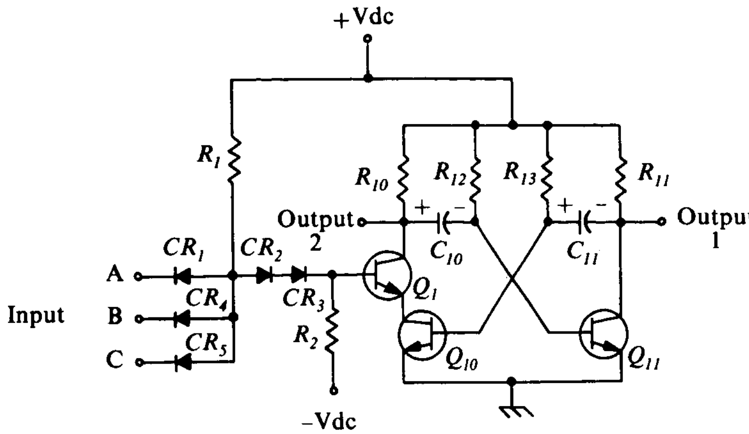
b

on the output indicates error-free operation and a down level indicates erroneous operation.

Component values and parts list were not available at the time of publication.

SOURCE: International Business Machines under contract to Marshall Space Flight Center (M-FS-234) B65-10047

Controlled Basic Oscillator



APPLICATION: This controlled oscillator circuit is a combination of a standard stroke gate and an astable multivibrator. It can be used as a clock in applications where synchronous timing is an important factor as in digital logic operations.

CIRCUIT DESCRIPTION: In this combination circuit, the transistor Q_1 is inserted between resistor R_{10} and transistor Q_{10} with R_{10} serving its normal function in the multivibrator as well as the function of the stroke gate.

The stroke gate is controlled by its one or more inputs at point A, B, or C. If the inputs are all open circuited, connected to +V directly, the transistor Q_1 is biased ON and presents a negligible resistance between R_{10} and Q_{10} of the multivibrator circuit. Under these conditions, the multivibrator performs in a normal manner. If any one of the inputs to the stroke gate is grounded, Q_1 is biased OFF and presents an extremely high resistance between R_{10} and Q_{10}. This action brings the junction of R_{10} and C_{10} to very nearly +V. The voltage rise is coupled through C_{10} to the base of transistor Q_{11} turning it ON. C_{10} charges to very nearly +V through R_{10} and the base-to-emitter junction of Q_{11}. The drop in voltage at the collector of Q_{11}, when it was turned ON, is transferred through C_{11} to the base of Q_{10}, reverse biasing the base emitter junction.

C_{11} then proceeds to charge through R_{13} and the collector-emitter of Q_{11} from near −V to a voltage near zero which is sufficient to forward bias the base-emitter junction of Q_{10}. C_{11} charging stops and the circuit remains stable until controlling voltage or signal at the stroke gate is removed.

When the controlling voltage at A, B, or C of the stroke gate is removed, Q_1 is biased ON. The voltage drop at the junction of Q_1 and R_{10} is coupled through C_{10} to turn Q_{11} OFF. Consistent with the turning off of Q_{11}, the restarted clock cycle commences.

DESIGN CONSIDERATION: By the proper selection of values, diodes CR_2 and CR_3 may be replaced by a resistor.

Component values and parts list were not available at the time of publication.

SOURCE: A. J. Kogan
Westinghouse Electric Corporation
under contract to
Manned Spacecraft Center
(MSC-59)

Section 9

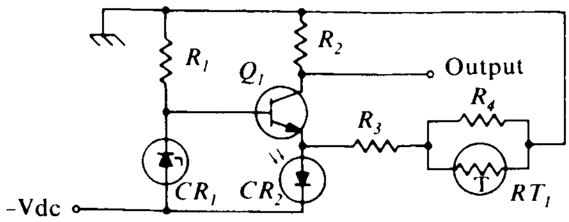
MISCELLANEOUS CIRCUITS

A DC-Coupled Photo-Diode Switch

APPLICATION: This circuit is useful for temperature compensation of direct-coupled photo-diode sensing devices and features low cost circuit components. It can be used in accurate light sensing and control applications and where temperature compensation is required.

CIRCUIT DESCRIPTION: The circuit level detects very slow sinusoidal type signals caused by light falling on a photo-diode. It allows the photo-diode to be dc coupled without detrimental temperature-dependent dark current variations.

A constant voltage is placed on the base of transistor Q_1 by the zener diode CR_1 and the resistor R_1. The photo-diode, CR_2, is placed in the emitter circuit of Q_1. With the absence of light on CR_2, it acts like a voltage source and reverse biases the base-to-emitter junction of Q_1. The dark current, or leakage, then is limited to the emitter-to-base current and the amount of current in the compensating network. Therefore, dark current variations are not sensed in the collector circuit of Q_1.



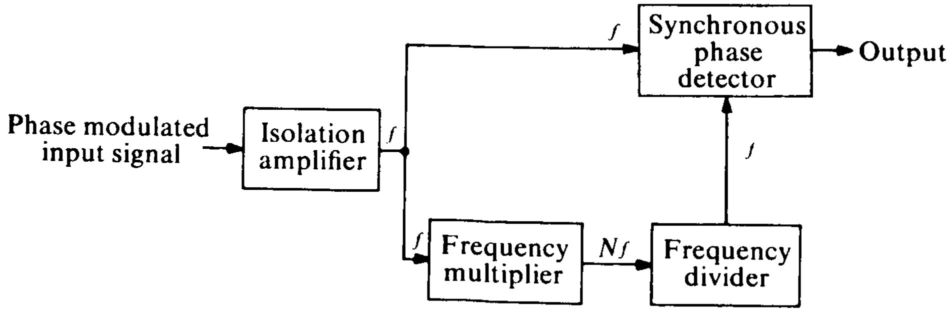
The light current variations due to temperature changes are corrected by a thermistor temperature compensating network.

Typical circuit elements and component values include:

Supply	-4 V dc
CR_1	1N758
CR_2	1N2175
R_1	1.2K
R_2	510K
R_3	82K
R_4	1.8 Ω

SOURCE: James O. Horsley
Radio Corporation of America
under contract to
Goddard Space Flight Center
(GSFC–195)

Self-Referencing Phase Detector



APPLICATION: The diagram shown outlines a phase detection circuit used to detect discrete-step, phase-modulated signals by synthesizing its phase reference signal from the phase-modulated input signal. It may be used for synchronizing transmitter-receiver functions or similar applications.

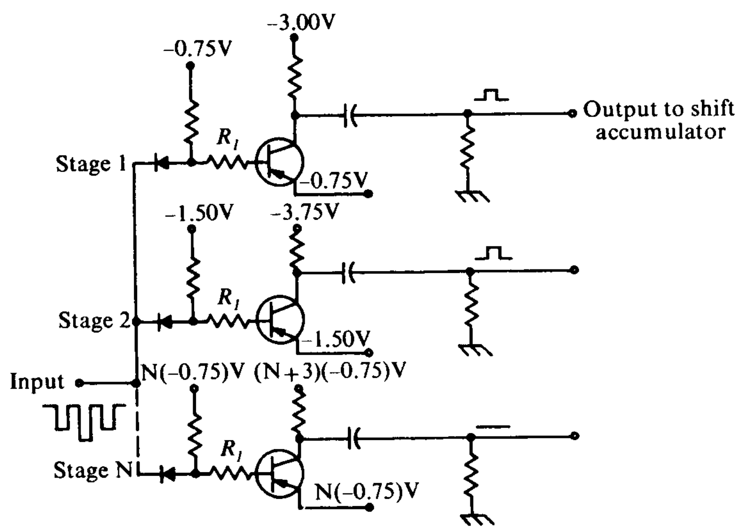
CIRCUIT DESCRIPTION: The output of the isolation amplifier (at input frequency f) is connected to both the frequency multiplier and the synchronous detector. The frequency multiplier uses the signal from the isolation amplifier as a control timing signal to generate an output at N times the input frequency. The multiplication factor, N, for a particular system is determined from the expression $N = 2\pi\ \Delta\phi$, where $\Delta\phi$ is the phase change per step in radians. A frequency multiplier is used because phase changes in the input signal do not appear in the multiplier output.

The output of the frequency multiplier (at a frequency Nf) goes to the frequency divided, where, after division by N, a constant-phase signal of frequency f is available as the reference signal in the synchronous detector. The synchronous detector compares the phase of the original signal from the isolation amplifier with the phase of the synthesized reference signal. The output of the detector is a dc voltage, the polarity of which changes each time the input signal changes phase.

DESIGN CONSIDERATION: The pulse rate and the carrier of the transmitted signal must be synchronized so that the phase change always occurs at the same point on the carrier wave shape. In a bi-phase modulation system, where digital information is transmitted in steps of 180° phase difference ($\Delta\phi = \pi$), the multiplication factor, N, is equal to 2.

SOURCE: Fairchild Stratos Corporation
under contract to
Marshall Space Flight Center
(M-FS-247)
B65-10080

Efficient Pulse Height Analyzer



APPLICATION: This is an example of a simple multistage transistor gating circuit that compares the input pulse heights to discrete reference voltages and operates at high pulse repetition rates.

CIRCUIT DESCRIPTION: Each pulse in a train of negative pulses is admitted simultaneously to the base of the transistor in each of the stages (1 to N). The transistors (base and emitter of each transistor) are biased by a reference voltage so that they produce an output voltage for any pulse height less (i.e., greater in absolute value) than the particular reference level. The reference levels are established in decreasing equal increments. The reference bias voltage for the first stage is –0.75 volt; for the second stage, –1.50 volts; and for the Nth stage, $N(-0.75)$ volts. The voltage references may be chosen so that the circuit measures any desired voltage difference, the minimum difference being determined by the transistor used.

When no input pulse is applied, all the transistors are turned OFF, because each transistor is biased to the same extent by the regulated power supplies V_1, V_2, to V_N. The diodes block interaction between stages, and thus prevent one stage from turning on another stage. When a negative pulse on the input terminal is less than —0.75 volt, for example, the first-stage transistor begins to conduct and an output voltage pulse appears at its collector. This pulse is then stored in the shift accumulator. As the input voltage continues to decrease to lower bias levels, succeeding stages turn ON, and their outputs are stored in the shift accumulator. The height of each pulse is read from the accumulator position that corresponds to the highest stage for that pulse.

DESIGN CONSIDERATION: The collector voltage supplies need not be closely regulated. For operation at low frequencies (less than 300 kc per sec) a single voltage supply with a resistive divider may be satisfactory for the base and emitter bias voltages. At higher frequencies, however, a separate regulated supply will be needed for each of these voltages and the operating speed of the analyzer can be increased by shunting each resistor R_1 with a capacitor.

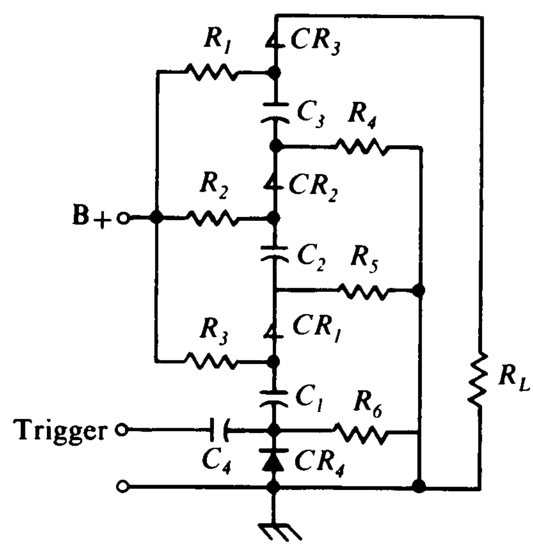
Component values and parts list were not available at the time of publication.

SOURCE: Space Technology Laboratories
under contract to
Western Operations Office
(WOO-046)
B65-10041

High Voltage Pulse Modulator

APPLICATION: A conventional circuit for producing high-voltage output pulses dissipates a portion of its theoretical output power across the charging resistors (sketch a). An improved circuit, sketch b, employs diodes that effectively disconnect the charging resistors from the circuit during the discharge cycle. This improved circuit is an approach to producing high-voltage modulation pulses by the use of simple low-voltage circuit components and can find use in many high-voltage pulse modulation applications.

CIRCUIT DESCRIPTION: The sketches show three parallel stages for charging, and a single stage for discharging the capacitors C_1, C_2, and C_3 in series through the load. Either of the circuits can theoretically employ as many stages as required to produce an output voltage of the desired magnitude.



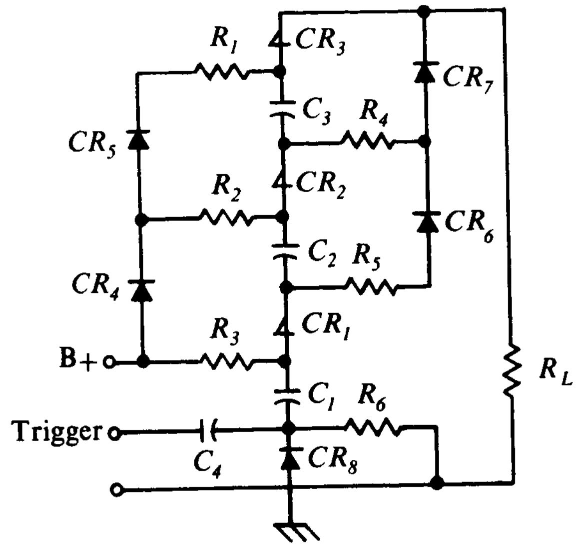
a
Conventional circuit

In sketch a, the capacitors C_1, C_2, and C_3 are charged to the B+ voltage through charging resistors R_1, R_2, and R_3. A trigger pulse applied to C_1 biases the four-layer diode CR_1 to a low-impedance state, opening a series conductive path from C_1 through CR_3 to impress the sum of the voltages across the three capacitors onto the load. The output pulse, however, also appears across the charging resistors, where I^2R losses occur. Since the maximum voltage drop occurs in R_1, this resistor cannot be a low-voltage component, and the effect of voltage gradients must be considered. Currents larger than the diode holding current will flow through the charging resistor, making it difficult to turn the circuit OFF before the capacitors are completely discharged.

In the improved circuit the diodes CR_4, CR_5, CR_6, and CR_7 effectively disconnect the charging resistors from the circuit during the discharge cycle. This circuit arrangement thus allows the use of low-voltage charging resistors and eliminates power loss through these resistors, as well as the problems of voltage gradients and power turnoff associated with the conventional circuit.

Component values and parts list were not available at the time of publication.

SOURCE: E. D. Green
Westinghouse Electric Corporation
under subcontract to
Manned Spacecraft Center
(MSC–14)
B64–10024



b
Improved circuit

GLOSSARY OF TERMS

Amplifier—Device employing the controlled flow of electrons for increasing amplitude of a signal in either or both current and voltage. (See also cascade amplifier, class A amplifier, class B amplifier, differential amplifier, magnetic amplifier, modulated amplifier, operational amplifier, and wideband amplifier.)

Amplitude modulation—Modulation in which the amplitude of a wave is the characteristic subject to variation.

Analog—A physical system on which the performance of measurements yields information concerning a class of mathematical problems.

Astable (free-running) multivibrator—A circuit which has two quasi-stable states. No trigger is required; a continuous waveform is generated.

Automatic frequency control (AFC)—An arrangement whereby the frequency of an oscillator is automatically maintained within specified limits.

Automatic gain control (AGC) — Reverse AGC is a term generally applied to a transistor amplifier which is gain-controlled by holding the collector voltage relatively constant and changing the current through the device. The expression "forward AGC" indicates a method wherein the collector-base (or collector-emitter) voltage is made to vary in accordance with collector current, the gain being directly dependent upon voltage across, and current through, the transistor. In choosing between the two methods, the desired end result of the AGC amplifier must be kept in mind and a comparison made as to the most practical and efficient method by which that result can be attained. Comparisons can be made in the areas of available power gain, gain variation, noise figure, overload characteristics, and d-c operating point.

Back bias—1. Degenerative or regenerative voltage which is fed back to circuits before its originating point. It is usually applied to a control anode of a tube. 2. Voltage applied to a grid of a tube (or tubes) to restore a condition which has been upset by some external cause.

Base region—The interelectrode region of a transistor into which minority carriers are injected.

Bias—The quiescent direct emitter current or collector voltage of a transistor. In a transistor amplifier, bias can be considered to be the direct current applied to the input terminal of the transistor (base or emitter) to establish an operating point on the load line of the output characteristic curve. (See also back bias.)

Bias voltage—Voltage applied or developed between two vacuum tube electrodes (generally the control grid and cathode) to influence the effect of the signal voltage in the input circuit of these two electrodes.

Binary-coded decimal system—A system of number representation in which each decimal digit is represented by a group of binary digits.

Bistable (flip-flop) multivibrator—A circuit with two stable states.

Blocking oscillator—A transformer coupled, feedback oscillator in which plate current flows for only one half cycle before the oscillation is halted due to blocking. The oscillation then ceases for a period determined by the time required for the circuit to become unblocked. The length of the current pulse is determined by the transformer resonance. The period of the pulse is determined by relaxation oscillator principles.

Bootstrap circuit—Amplifier in which the output load impedance appears between the negative end of the plate supply and the cathode of the amplifier tube, the signal voltage being applied between the grid and the cathode. The bootstrap circuit differs from a cathode follower in that amplification is achieved by applying the input signal between grid and cathode where it does not suffer the degeneration caused by the output voltage appearing across the cathode resistor.

Breakdown voltage—Breakdown voltages are measured at a specific current level which is set high enough to be in the constant-voltage region of the breakdown characteristic. Measurements in this region, however, may result in damage to the device from excessive power dissipation. For this reason, breakdown characteristics are usually guaranteed as a leakage current which is measured in the nearly constant current region of the characteristic.

Capacitance—1. Ability to store electrical energy, measured in farads, microfarads, or picofarads. 2. Property of a capacitor which determines the amount of electrical energy which can be stored in it by applying a given voltage. 3. Property of two or more bodies which enables them to store electrical energy in an electrostatic field between them. (See also effective capacitance and input capacitance.)

Capacitor—Device consisting essentially of two conducting surfaces separated by an insulating material or dielectric. A capacitor stores electrical energy, blocks the flow of direct current, and permits the flow of alternating current to a degree dependent on the capacitance and the frequency.

Carrier frequency—1. Frequency of an unmodulated carrier wave. 2. Number of cycles per second (frequency) of a carrier wave.

Cascade amplifier—Amplifier of several stages, the output of one being the input of the next.

Cathode—1. Negatively charged pole, electrode, conductor, or element from which current leaves. 2. Primary source of electrons in a vacuum tube. 3. General term for a negative electrode.

Chopper—Device for interrupting a current or a light beam at regular intervals. Choppers are frequently used to facilitate amplification.

Circuit—1. Electronic path between two or more points. 2. Number of conductors connected together for the purpose of carrying an electrical current. 3. Connected assemblage of electical components such as resistors, capacitors, and inductors having desired electrical characteristics. (See also Bootstrap circuit, push-pull circuit, and rejector circuit.)

Class A amplifier—An amplifier in which the bias and alternating signal are such that output current in a specific device flows at all times.

Class B amplifier—A class B stage may be defined as one biased close to cutoff, so that any upward signal fluctuations turn the active device ON, while for downward fluctuations, it remains OFF.

Collector—1. An electrode through which a flow of minority carriers leaves the interelectrode region. 2. Electrode in a velocity-modulated vacuum tube on which the spent electrons are collected.

Current—Drift of electrons past a reference point. The passage of electrons through a conductor, measured in amperes. (See also interbase current, leakage current, plate current, and saturation current.)

Damping diode—Vacuum tube which damps the positive or negative half-cycle of an ac voltage.

Differential amplifier—The emitter-coupled differential amplifier is a versatile input stage which offers voltage-drift compensation between similar transistors.

Digital computer—A computer in which information, numerical or otherwise, is represented by means of combinations of characters in such a way that the number of distinguishable combinations is much greater than the number of distinguishable characters.

Diode—Vacuum tube with two electrodes — a cathode and a plate—used principally as: 1) detector and 2) rectifier for converting alternating currents to pulsating current. (See also damping diode, junction diode, photodiode, PNPN (four layer) diode, tunnel diode, and zener diode.)

Drift—It is customary to specify drift in terms of the change of input voltage or current required to maintain constant output conditions when the parameters of the amplifier vary. If several stages are cascaded, the equivalent input drift for the amplifier will be determined by the input stage, providing that stage has moderate gain.

Driver stage—The stage designed to supply the input signal power required by the last or final stage of an amplifier.

Dynamic range—1. Range over which the input signal amplitude may vary and yet maintain an undistorted output. 2. Transmission system differences in decibels between the noise level of the system and its overload level.

Effective capacitance—The total capacitance existing between any two given points of an electric circuit.

Electron—The electrons in the conduction band of a solid, which are free to move under the influence of an electric field.

Emitter—An electrode from which a flow of minority carriers enters the interelectrode region.

Fall time—Time required for the voltage or current in a circuit to rise to 63 percent of its final value, or fall to 37 percent of its initial value, as a result of step function input.

Feedback—Feedback techniques are commonly used in transistor amplifiers to reduce the effects of transistor parameter variations on gain and distortion, and to improve the characteristics of the amplifier.

Field effect transistor—A transistor utilizing the change of barrier thickness with applied voltage as a control mechanism.

Filter—An entity or device for eliminating (or reducing) certain waves or frequencies while leaving others relatively unchanged. The waves may be sound waves, electromagnetic waves or they may be waves in the optical region.

Frequency—1. Number of recurrences of a periodic phenomenon in a unit of time. In specifying the electrical frequency, the unit of time is the second. 2. Radio frequencies are normally expressed in kilocycles (kc/s) per second and in megacycles per second (mc/s). (See also carrier frequency.)

Frequency modulation—Modulation of a sine-wave carrier in which the instantaneous frequency of the modulated wave differs from the carrier frequency by an amount proportional to the instantaneous value of the modulating wave.

Frequency multiplication—Frequency multiplication is usually accomplished by feeding a fundamental frequency signal into a nonlinear network; from the harmonics thus produced, one multiple of the fundamental frequency is isolated and amplified. The transistor's emitter-base diode characteristic is often used as the nonlinear network required.

Frequency stability—Ability of an oscillator to maintain its operation at a constant frequency.

Gain—Ratio of output to input voltage, current, or power, usually expressed in decibels. Gain and transmission gain are general terms used to denote an increase in signal power in transmission from one point to another. Gain is usually expressed in decibels and is widely used to denote transducer gain.

Gain control—1. Control connected so that it can change the overall gain of an amplifier. 2. Any volume control.

Grid—1. Any of those elements within an electron tube which primarily govern the number of cathode-emitted electrons which arrive at the anode. 2. Electrode consisting of a wire mesh placed between the cathode and the anode in an electron tube so that the electrons must pass through it, and used as a control of the tube current by means of variations in the negative grid potential. 3. Metallic (commonly lead) part of either of the electrodes of a storage cell.

Harmonic oscillator—1. Production of harmonic frequencies at the output by the nonlinearity of a transducer when a sinusoidal voltage is applied to the input. Amplitude of distortion is usually a function of the amplitude of the input signal. 2. Condition that exists in the output of an amplifying circuit when harmonics, added during the process, alter the signal waveform. Impairment of fidelity caused by the generation of new frequencies that are harmonics of the frequencies contained in the applied signal.

Impedance—1. Ratio of the effective value of the potential difference between the terminals under consideration to the effective value of the resulting current, where there is no source of power in the portion of the circuit under consideration. 2. That property of an electrical circuit which opposes the flow of current. While a resistance is an impedance, the term is usually reserved for the opposition to current flow offered by inductors, capacitors, or combinations of both. (See also input impedance, matched impedance, output impedance, plate impedance, and plate-load impedance.)

Input capacitance—Sum of the direct capacitances between the control grid and the cathode and such other electrodes that are operated at the alternating potential of the cathode. This is not the effective capacitance.

Input impedance—Impedance presented by a device to the source.

Interbase current—In a junction tetrode transistor, the current that flows from one base connection to the other through the base region.

Inverter—A device for converting dc to ac.

I-type, or intrinsic semiconductor—A semiconductor in which the electrical properties are essentially not modified by impurities or imperfections within the crystal.

Junction—In a semiconductor device, a region of transition between semiconducting regions of different electrical properties.

Junction diode—A semiconductor diode whose non-symmetrical volt-ampere characteristics are manifested as a result of the junction found between N-type and P-type semiconductor materials. This junction may be either diffused, grown, or alloyed.

Leakage current—A leakage current is measured at a specified reverse voltage applied across the appropriate terminals of a transistor. This voltage is usually one-half to two-thirds of the value of the breakdown voltage. Measurement of this sort is often used to guarantee a minimum breakdown voltage. Typical leakage parameters measured are I_{cbo} (collector-base-leakage, emitter open), I_{ceo} (collector-emitter-leakage, base open), and I_{ebo} (emitter-base-leakage, collector open.)

Low-level audio stage—One of the most-used circuits in transistor applications is the cascaded common-emitter audio amplifier. This circuit performs a variety of functions, is fairly easy to design, and gives good performance. The function of a low-level amplifier is to raise a signal level from the millivolt range to a workable level of several volts. For example, the input signal may be derived from the output of a piezoelectric crystal, while the output may be required to drive a power amplifier.

Magnetic amplifier—A device using saturable reactors either alone or in combination with other circuit elements to secure amplification or control.

Matched impedance—Condition which exists when two coupled circuits are adjusted so that the impedance of one circuit equals the impedance of the other.

Modulated amplifier—Amplifier stage of a transmitter in which the radio frequency carrier is electrically varied or modulated in accordance with another signal such as voice, tone, or visual signals.

Modulation—Process in which the amplitude, frequency, or phase of a carrier wave is varied with time in accordance with the waveform of superimposed intelligence. (See also amplitude modulation and frequency modulation.)

Monostable—Term used to describe a circuit with one stable state and one quasi-stable state. The circuit requires an external trigger to perform one cycle.

Monostable multivibrator—A multivibrator having one stable state and one quasi-stable state. A finite time after it is set in the quasi-stable state by an external signal, it returns to the stable state. Also known as delay multivibrator, one-shot, or single shot.

Multivibrator—1. Form of relaxation oscillator which comprises two stages so coupled that the input of each one is derived from the output of the other. 2. A multivibrator is termed free running or driven, according to whether its frequency is determined by its own circuit constants or by an external synchronizing voltage. (See also bistable (flip-flop) multivibrator and monostable multivibrator.)

Negative resistance—A negative resistance exists in a circuit when the derivative of voltage across the circuit with respect to the current through the circuit has a negative value.

Noise ratio—The ratio of the available noise power at the output of a circuit divided by the noise power at the input.

N-type semiconductor—An extrinsic semiconductor in which the conduction electron density exceeds the hole density.

Ohmic contact—A contact between two materials, possessing the property that the potential difference across it is proportional to the current passing through.

Operational amplifier—By the use of feedback elements, certain amplifiers may be made to produce an output which is proportional to the algebraic sum, the time derivative, the integral with respect to time, or simply a multiple of the input signal voltage or other mathematical operations. Such designs are widely used as building blocks for analog computers. Because of their mathematical versatility, they are called operational amplifiers.

Oscillator—A nonrotating device for producing alternating current, the output frequency of which is determined by the characteristics of the device. (See also blocking oscillator, harmonic oscillator, and relaxation oscillator).

Output impedance—Impedance presented by a device to the load.

Parallel—Connected to the same pair of terminals, so that current branches out over two or more paths.

Parallel logic—Simultaneous transmission of, storage of, or logical operations on the parts of a word, character, or other subdivision of a word, using separate facilities for the various parts.

Parallel resonance—Form of resonance which exists when a capacitor and an inductor are connected in parallel. Parallel resonance is characterized by high attenuation at the resonant frequency.

Phase shift—Change in the phase of a sinusoidal wave.

Phase shifter—Device for altering the phase of a wave.

Photo-diode—A two-electrode semiconductor device sensitive to light. Photoconductive cells are photodiodes in which the resistance decreases when illuminated. Photoelectric cells are self-generating photodiodes.

Phototransistor—A thin wafer of germanium in which holes are generated by light absorption, and produce a multiplied photo-current by transistor action at the collector.

Plate current—Electron flow from the cathode to the plate inside the vacuum tube.

Plate impedance—Plate voltage change divided by the resulting plate current change in a vacuum tube, all other conditions being fixed.

Plate-load impedance—Impedance in the plate circuit across which the output signal voltage is developed by the alternating component of the plate current.

PN junction—A region of transition between P- and N-type semiconducting material.

PNPN (four-layer) diode—A semiconductor device which may be regarded as a two-transistor structure with two separate emitters feeding a common collector. This combination constitutes a feedback loop which is unstable for loop gains greater than unity. This instability results in a current which increases until ohmic circuit resistances limit the maximum value. This gives use to a negative resistance region which may be utilized for switching, or for waveform generation.

Potentiometer—Variable voltage divider. A resistor that has a variable contact arm so that any portion of the potential applied between its ends may be obtained.

P-type semiconductor—An extrinsic semiconductor in which the hole density exceeds the conduction-electron density.

Punch-through—With a sufficiently high collector voltage in a junction transistor with very narrow base region, the space-charge layer may extend completely across the base region, causing an emitter-to-collector breakdown that is called punch-through.

Push-pull circuit—A circuit employing two similar transistors with their bases connected in phase opposition and collectors in parallel to a common load, and usually used as a frequency multiplier to emphasize even-order harmonics.

Rectifier—1. A device having an asymmetrical conduction characteristic, employed in such a manner as to convert alternating current into unidirectional current. In amplitude modulation detection, recovery of original signals is frequently accomplished by a rectifier. 2. Device that converts alternating current into unidirectional current by permitting appreciable current flow in one direction only. (See also SCR (silicon controlled rectifier.)

Reference time (T_0)—An instant near the beginning of switching chosen as an origin for time measurements.

Rejector circuit—Name sometimes given to a parallel resonant circuit that is tuned to the frequency of an undesired signal and connected to suppress or reject that signal.

Relaxation oscillator—A system that has two quasi-stable states or configurations, such that the passage to either state causes the other to become the stable one.

Resistor—Electrical component which offers resistance to the flow of current.

Rise time—Time required for the voltage or current in a circuit to rise to 63 percent of its final value, or fall to 37 percent of its initial value, as a result of step function input.

Saturation—1. Condition in electron tubes, under which maximum current is passing through the cathode circuit. 2. Condition which exists in a circuit when an increase in the actuating component produces no further increase in the resultant effect.

Saturation current—In a reverse-biased junction, the current due to thermally generated electrons or holes. In electron tubes, a condition under which maximum current is passing through cathode circuit.

Schmitt trigger—Regenerative circuit which changes state abruptly when the input signal crosses specific dc triggering levels.

SCR (silicon controlled rectifier)—A silicon controlled rectifier (SCR) is much like an ordinary rectifier which has been modified to block in the forward direction until a small signal is applied to the gate lead. After the gate signal is applied, the SCR conducts in the forward direction with a forward characteristic very similar to that of an ordinary rectifier and will continue conduction even after the gate signal is removed.

Semiconductor—An electronic conductor, with resistivity in the range between metals and insulators, in which the electrical charge carrier concentration increases with increasto 0.632 times the total change that will occur. In a capacitor-resistor circuit, it is the number of seconds required for the capacitor to reach 63.2 percent of its full charge after a voltage is applied. In an inductor-resistor circuit, it is the number of seconds required for the current to reach 63.2 percent of its final value. The time constant in seconds of an inductor having an inductance L in henrys and resistance R in ohms is L/R. The time constant of a capacitor having a capacitance C in farads in series with a resistance R in ohms is RC.

Time delay—The time required by a specific voltage or current to travel through a circuit.

Toroid—A surface, or its closed solid, generated by any closed plane rotating about a straight line in its own plane—the resulting configuration being doughnut shaped.

Transducer—1. Device by means of which energy can flow from one or more transmission systems to one or more other transmission systems. 2. Energy transmitted by these systems may be of any form (for example, it may be electrical, mechanical, or acoustical), and it may be of the same form or different forms in the various input and output systems.

Transient—That part of the forced oscillation of a linear system which decays more or less rapidly after the imposition of force; to be distinguished from the steady state.

Transistor—An active semiconductor device with 3 or more electrodes. (See also field effect transistor, phototransistor, and unipolar transistor.)

Transistor current gain (α)—The small-signal short-circuit forward current ratio of the partial of I_c divided by the partial of I_E with V_{cb} held constant.

Transistor noise figure—The noise figure the device can yield under the specified conditions of source resistance, frequency, and bias level. The ratio of the input signal-to-noise power divided by output signal-to-noise power yields the noise figure of the device.

Transistor parameter t_d (delay time)—The time interval between the use of a pulse applied to the input terminals and the rise of the minority-carrier generated pulse appearing at the output.

Trigger—To set off or initiate a certain action in an electrical circuit by the application of a pulse of voltage.

Tuned circuit—Circuit consisting of inductance and capacitance which can be adjusted for resonance at a desired frequency.

Tunnel diode—A semiconductor junction diode which has a negative resistance region in its forward volt-ampere characteristic.

Unipolar transistor—A transistor which utilizes charge carriers of only one polarity.

Variable resistor—Resistor whose electrical value can be changed mechanically.

Varistor—A two-electrode semiconductor device having a voltage-dependent nonlinear resistance.

Voltage—1. Term used to signify electrical pressure. Voltage is a force which causes current to flow through an electrical conductor. 2. Voltage of a circuit—the greatest effective difference of potential between any two conductors of the circuit concerned. (See also breakdown voltage and signal voltage.)

Voltage regulator—Automatic voltage regulators are relied upon for maintenance of constant generator voltage. Alternator-voltage regulators have, for all practical purposes, become limited to four distinct types, vibrating, magnetic, rheostatic, and electronic. Dc regulators are usually rheostatic.

Wave shape—Graph of the wave as a function of time or distance.

Wideband amplifier—An amplifier having uniform response over many decades of frequency.

Zener diode—A junction diode designed to effect nondestructive "breakdown" from a very high resistance to a very low resistance at a predetermined voltage level.

ing temperature over some temperature range. Certain semiconductors possess two types of carriers, namely, negative electrons and positive holes. (See also I-type or intrinsic semiconductor, N-type semiconductor, and P-type semiconductor.)

Shunt—1. Precision low-value resistor placed across the terminals of an ammeter to increase its range. 2. Any part connected, or the act of connecting any part, in parallel with some other part. 3. Branch of an electric circuit having its winding in parallel with the external or line circuit.

Signal—1. Any transmitted electrical impulse. 2. A wave that conveys desired intelligence. The signal may consist of an electromagnetic wave in space, or the current in or voltage impressed upon a circuit element.

Signal-to-noise ratio—1. Ratio of the magnitude of the signal to that of the noise; often expressed in decibels. This ratio is expressed in many different ways; for example, in terms of peak values in the case of impulse noise and in terms of root-mean-square values in the case of random noise, the signal being assumed sinusoidal. 2. Comparison of the amount of signal to the amount of noise by means of a fractional ratio, measuring both elements in the same units. 3. Ratio of the intensity of the desired signal to that of undesired noise signal.

Signal voltage—Effective (root-mean-square) voltage value of a signal.

Silicon—Nonmetallic element which is a semiconductor and used as transistor material.

Sine wave—Wave in which the amplitude varies as the sine of the angle; the waveform of a normal alternating current or voltage.

Slope—The essentially linear portion of the grid-voltage, plate-current characteristic curve of a vacuum tube, on which the operating point is chosen when linear amplification is desired.

Solid-state devices—Devices which utilize the electric, magnetic, and photic properties of solid materials. For example, binary magnetic cores, transfluxors, transistors, magnetic amplifiers, etc.

Square wave—Periodic wave which alternately for equal lengths of time assumes one of two fixed values, the time of transition being negligible in comparison.

Squelch—To automatically quiet a receiver by reducing its gain in response to a specified characteristic of the input.

Storage time—The time interval between the fall of a pulse applied to the input terminals and the fall of the carrier-generated pulse at the output terminals.

Sweep—Traversing of a range of values of a quantity for the purpose of delineating, sampling, or controlling another quantity.

Switching—Making, breaking, or changing the connections in an electrical circuit.

Temperature compensation—The process whereby the effects of an increase or decrease in ambient temperature are cancelled (e.g., as in the case of an oscillator that is required to maintain a stable output frequency regardless of ambient temperature changes.)

Tetrode—Four-electrode electron tube containing an anode, a cathode, a control electrode, and one additional electrode, ordinarily in the nature of a grid.

Thermistor—An electronic device that makes use of the change of resistivity of a semiconductor with change in temperature. They are useful for temperature measurement and control, to compensate for positive temperature coefficient of resistance of metallic conductors, and for current surge suppression.

Thermocouple—1. Device consisting of two dissimilar metals in physical contact, thereby forming a thermojunction across which a voltage is developed when the junction is heated. 2. An instrument comprising a thermocouple, or thermocouples, connected to a meter calibrated in units of temperature is one of many types of pyrometers.

Time constant—Time required for an exponential quantity to change by an amount equal

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